13

Energy Research Advisory Board
to the
United States Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585
(202) 586-5444

8/30/89

To the Cold Fusion Panel

Circulated for your information

WLW

Richard L. Garwin
IBM Research Division
Thomas J. Watson Research Center
P.O. Box 218
Yorktown Heights, NY 10598
(914) 945-2555

August 23, 1989

Dr. William L. Woodard
Cold Fusion Panel Secretary
Energy Research Advisory Board
to the
United States Department of Energy
1000 Independence Avenue, S.W.
Washington, DC 20585

Dear Bill,

Enclosed is a letter from Michael Nauenberg to H. Rossi at the University of Utah, together with several letters to Nauenberg that followed. I thought they might be of interest to the Cold Fusion Fusion Panel.

I include also a reply from J.C. Hill to my letter to him of 08/16/89. He has provided a corrected version of the manuscript, with changes on pages 6.9, 7.1, 7.7, and in Figure 1.

I have heard of careful work by Maurice Chemla (Paris) in which no heat effects were found in electrochemical cells, and also no excess tritium.

Very best regards.

Sincerely yours,

Richard L. Garwin

Encl:
07/00/89 LTR M. Nauenberg to H. Rossi re cold fusion with reply from Rossi, Petrasso, and Anon. (070089..MN)
08/18/89 LTR J.C. Hill to RLG including corrected version of "Search for Cold Fusion ..." by J.C. Hill et al, with changes on pages 6.9, 7.1, 7.7, and in Figure 1. (081889.JCH)

Also Adjunct Professor of Physics at Columbia University
(Views not necessarily those of IBM or Columbia)

UNIVERSITY OF CALIFORNIA, SANTA CRUZ

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PHYSICS DEPARTMENT

SANTA CRUZ, CALIFORNIA 95064

July 11, 1989

Professor H. Rossi
Acting Director Cold Fusion Center
University of Utah
Salt Lake City, Utah

Dear Professor Rossi,

I was appalled by the recent article in the June 29 issue of Nature by Fleischmann, Pons and Hawkins on measurements of the spectrum of gamma rays from their electrolysis experiment. Without any explanation whatsoever, the controversial peak at 2.2 Mev, which they previously interpreted as evidence for neutrons from cold fusion, now reappears shifted to 2.496 Mev. Furthermore, they state that the search for the 2.2 Mev peak "does not seem to be feasible using NaI detectors". This is completely unjustified as was demonstrated by the MIT group of Petrasso et. al.

I have followed in some detail the cold fusion saga since it began almost four months ago. I visited your laboratories as well as those of Los Alamos, Livermore and Cal Tech and talked with many of the scientists involved in these experiments. I have also examined the theoretical issues involved (enclosed). It is now fairly clear that there does not exist any correlation whatsoever between the claimed heat excess and nuclear fusion in electrolysis experiments. Whatever is going on in the cells should be clarified, but calling it cold fusion is now totally unjustified. All the previous tests finding neutrons, gamma rays, He and tritium have been found to be flawed. Hence the recent claim of Pons of a device that provides hot water based on cold fusion as reported in the Deseret is misleading, to say the least.

This charade has already done great damage to the reputation of the Chemistry Department at the University of Utah. If continued it will do irreparable damage to the credibility of the whole university. Therefore, I would like to urge you to do whatever is possible to put an end to it.

Sincerely,

MNauenberg

Michael Nauenberg
Professor of Physics and
Director of the Institute for Nonlinear Sciences.

cc: Dr. Raymond C.Hixon, Chairman of the State Fusion Energy
Advisory Council
Prof. Wilford Hansen, Utah State University

071189..MN

THE
UNIVERSITY
OF UTAH

2416 Henry Eyring Building
Telephone: 801-581-6796
FAX: 801-581-6674

July 26, 1989

Professor Michael Nauenberg
Professor of Physics
Director for the Institute for Nonlinear Sciences
University of California, Santa Cruz
Santa Cruz, CA 95064

Dear Dr. Nauenberg:

I thank you for your interest in the health of the University of Utah, for your comments on the letter of Fleischmann, Pons and Hawkins and for the reprint of your article. I agree with your implication that the phenomenon discovered by Fleischmann and Pons is not yet on a firm, sound basis, and that some claims, particularly as interpreted and reported by the press, have not been substantiated. I disagree however that it is clear that *there does not exist any correlation whatsoever between the claimed heat and nuclear fusion...* ; I think that the statement in the next to last paragraph of your article is a more accurate expression of skepticism.

Perhaps you do not agree with me that a very significant and surprising phenomenon has been discovered and repeated sufficiently (although with a high degree of irreproducibility) to warrant continued scientific investigation. I am convinced that the science must and will go on. It is also plausible that this could have practical applications. In any event, any apparent source of power production should be studied until understood.

For the University and the State of Utah to be positioned to participate in the development of this resource (should it turn out that there is such a resource) it is essential that we shall have continued with the science and are set up to move quickly into the development phase. We cannot wait until others have confirmed and moved ahead with this discovery; by then it will be too late for Utah. I am very painfully aware of the damage done to our reputation and of the dangers that lie ahead. But I also see an

Department of Chemistry
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Salt Lake City, Utah 84112

opportunity; perhaps a slim one, but a great one. If we are to realize it, we have no choice but to proceed with our plans and to continue the science.

Sincerely,

Hugo Rossi

Hugo Rossi, Interim Director
Cold Fusion Research Project

P. S. According to my dictionary, a *charade* involves two teams acting out certain concepts or roles. I want to assure you that I am doing all that I can to put an end to the charade.

cc: Dr. Raymond C. Hixon, Chairman of the State Fusion Energy Advisory Council
Professor Wilford Hansen, Utah State University
Dr. Chase N. Peterson, President, University of Utah
Dr. James J. Brophy, Vice President for Research, University of Utah

HR:rgt

LABORATORY Institute for Physical Research and Technology
Iowa State University Ames, Iowa 50011-3020

August 18, 1989

Dr. Richard L. Garwin
IBM Research Division
Thomas J. Watson Research Center
P.O. Box 218
Yorktown Heights, NY 10598

Dear Dr. Garwin:

Thank you for your letter and comment on Fig. 1 and the calculations. I fixed the figure and Jim Vary wrote some explanation concerning your theory questions which are incorporated in a new version. If you have any more theory questions, please address them to Jim Vary at (515) 294-8894 or JVARY@ALISUVAX who did the calculations.

We appreciate your comments and have enclosed an updated version for you.

Sincerely,

John C. Hill

John C. Hill
Professor of Physics

JCH/em

Enclosure

cc: J. P. Vary

Changes on pp 6.9
7.1
7.2,
Fig. 1

081889.JCH

Operated for the U.S. Department of Energy Under Contract W-7405-Eng-82

Plasma Fusion Center
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139
Telephone: 617/253-8100

July 26, 1989

Professor Michael Nauenberg, Director
Institute for Nonlinear Science
Physics Department
University of California, Santa Cruz
Santa Cruz, California 95064

Dear Professor Nauenberg:

Thank you for your letter of July 17 addressed to Professor R. R. Parker regarding the Fleischmann/Pons' paper on γ rays. My information is very similar to that contained in your letter. Specifically, a couple of weeks ago Michael Salamon of the Utah Physics Department showed me γ-ray spectra he obtained in Pons' laboratory, and, not surprisingly, none of the artifacts (peaks No. 7, 8, and 9, as we identified) are present in the high energy channels. Also not surprisingly, the spectrum over a "boiling cell" was identical to that of the background. Hopefully Michael will publish these data in the very near future. He also mentioned Hoffman's preamplifier problem.

Incidentally, I was very thankful--though quite surprised--that Fleischmann et al went ahead with the publication of their γ spectra. I wrote John Maddox a detailed critique of their work, and a large part of it had been transmitted to them. Fortunately through the publication of their spectra, Fleischmann et al unambiguously resolved many issues that would have lingered on and on.

I enjoyed the paper that you and Steve Koonin published in the 29 June issue of Nature.

Sincerely,

Richard Petrasso

Richard D. Petrasso
Physicist

July 27th, '89

Michael Nauenberg
Professor of Physics
Director, Institute for
Nonlinear Sciences
University of California
Santa Cruz, CA

ANON

Dear Professor Nauenberg,

I am writing to you relative to the column on the left printed in The Public Forum of The Salt Lake Tribune of 7/22/'89.

Not Justified

I have followed in some detail the cold fusion saga since it began almost four months ago. I visited the laboratories at the University of Utah as well as those at Los Alamos, Livermore, and Cal Tech, and talked with many of the scientists involved in these experiments. I have also examined the theoretical issues involved which have been published in the June 29 issues of Nature.

It is now fairly clear that there does not exist any correlation whatsoever between the claimed heat excess and nuclear fusion in electrolysis experiments.

Whatever is going on in the cells should be clarified, but calling it cold fusion is now totally unjustified. All the previous tests finding neutrons, gamma rays, He (helium) and tritium have been found to be flawed. This conclusion has also been reached by the special panel set up by the Department of Energy to study the issue of cold fusion. Hence the recent claim of Pons of a device that provides hot water based on cold fusion reported in the *Deseret News* is misleading, to say the least.

This charade has already done great damage to the reputation of the Chemistry Department at the University of Utah. If continued, it will do irreparable damage to the credibility of the whole university.

MICHAEL NAUENBERG
Professor of Physics
Director, Institute for Nonlinear Sciences
University of California
Santa Cruz

S.L.T.
7/22/89

Did you know (??) that even as there "does not exist any correlation whatsoever between the claimed heat excess and nuclear fusion in electrolysis experiments" (as you have noted), a panel of top Utah people known as The State Fusion/Energy Advisory Council on Friday, July 21st, did OK $5 million of state monies to be released to the University of Utah for its contraversial nuclear-fusion research?

This decision, of itself, is a revelation that could only have 'gone down' in the state of Utah. Nowhere else. At least, I think it unlikely it could happen anywhere else. But why Utah?

Because Utah and Utah people are a unique form of human phenomenon. They have the profound ability to want to believe something is so . . . exists, that is . . . and via the power of this belief, lo!! . . . it does exist. And they then so act. Belief and what belief tells them becomes their 'world of reality'. Professor Nauenberg, truly . . . TRULY . . . it is an absolutely incredible phenomenon.

Let me try and be more specific. You know, and I know, that nuclear-fusion research does exist. It exists at Princeton and Lawrence Livermore, naming two of the centers of such research. And it involves the creation of very high temperatures . . . the temperatures at which fusion can and does take place.

But now we here in Utah are to undertake cold-fusion research with $5 million of so-called 'seed-money'. And we are doing this because all manner of so-called experts BELIEVE nuclear fusion . . . cold nuclear fusion . . . did take place in a 'bottle'. And speaking of a 'bottle' did you know that after a walk in the woods years ago

successive pages not ~~[illegible]~~ mailed

Search for Cold Fusion Using Pd-D_2O Cells and Ti-D Mixtures[1]

John C. Hill,[2] C. Stassis,[2] J. Shinar,[2] A. I. Goldman,[2] R. Folkerts,[2]
D. D. Schwellenbach,[2] D. T. Peterson,[2] C. Widrig,[2] M. Porter,[2]
C. J. Benesh,[3] and J. P. Vary[3]

We have searched for cold fusion produced in an electrolytic cell with Pd cathode and Pt anode. The electrolyte was 0.1 molar LiOD in 99.8% D_2O. A 2 mm rod of polycrystalline Pd and a 4 mm rod of single crystal Pd were used. No radiation was detected above background by a BF_3 neutron and Ge γ-X detector. The D_2 loading of the Pd was 0.8 D per Pd atom reaching saturation after 4 hours. We also attempted to duplicate the work of Scaramuzzi and coworkers on the Ti-D_2 system. Both powder and pieces of Ti were used. The material was cycled several times between 1100 K and 77 K. No neutron, γ or X-ray emission above background was observed. The results of a barrier penetration calculation for H-like atoms are presented. The high fusion rates reported for PdD_x are much larger than those expected from theoretical calculations on these systems.

KEY WORDS: Cold fusion; Pd-D_2O cells; Ti-D_2 systems;
barrier penetration calculations.

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[1] This work supported by USDOE under Contract Nos. W-7405-ENG-82 and DE-FG02-87ER40371.

[2] Ames Laboratory, Iowa State University, Ames, Iowa 50011 U.S.A.

[3] Iowa State University, Ames, Iowa 50011 U.S.A

INTRODUCTION

Recent claims of the observation of cold fusion in Pd-D_2O cells by Fleischmann, Pons, and Hawkins,[1] and Jones et al.[2] have resulted in a flurry of activity by experimentalists to verify their claims and by theorists to devise a mechanism to account for cold fusion. Also of interest are claims by De Ninno et al.[3] who have observed bursts of neutrons emitted by Ti-D_2 systems during temperature cycling. Others have claimed to observe neutrons, radiations, and/or excess heat in Pd-D_2O systems and neutron emission from Ti-D_2 systems. There have been numerous attempts by a number of other investigators to reproduce the above mentioned "positive" results without success.

The Ames Laboratory group has carried out a number of experiments to search for radiation emitted in cold fusion from Pd-D_2O cells and Ti-D_2 gas systems using BF_3 neutron counters and Ge γ-X detectors. First we discuss our results from Pd-D_2O cells and Ti-D_2 systems and a search for cold fusion in $LaHD_2$ powder through the $p+d \rightarrow {}^3He + \gamma$ reaction is described. Next, the results of a simple barrier penetration calculation are given. Lastly, our results are summarized and conclusions given.

THE Pd-D_2O CELL EXPERIMENTS

Construction of Pd-D_2O Cells and Detectors

The electrolyte used in the Pd-D_2O cells was 99.8% D_2O made 0.1 molar in LiOD by dissolving a weighted amount of chemically pure Li metal in the D_2O. The total volume of the electrolyte was 160 ml in a cylindrical glass or teflon container with a teflon top. The temperature of the electrolyte was monitored with a Fe-constantan thermocouple and the current to the cell was supplied by a constant current source. The cylindrical anode was made of Pt wire and surrounded a thin Pd rod which served as the cathode. The cathode was always completely submerged in the electrolyte.

In the first of two runs, the cathode was a polycrystalline rod of Pd, 2 mm in diameter by 5 cm long, swaged to size from an arc-melted finger and annealed under vacuum at 650°

C. The evolved gases from electrolysis were allowed to escape and the D_2O was periodically replenished. A current of 0.95 A was supplied to the cell providing a current density of 0.30 A/cm^2 at the cathode. This run lasted for a total of 14 days.

For the second run, several improvements in the Pd-D_2O cell were made. The atmosphere above the electrolyte was dry N_2 gas continuously supplied from a tank, with the excess discharged through an oil bubbler. The electrolyte volume was kept constant by a "chicken feeder" type arrangement. The cathode was a thin rod of single crystal Pd, 4 mm in diameter and 5 cm long. A current of 0.92 A was supplied to the cell, providing a current density of 0.15 A/cm^2 at the cathode. This run lasted a total of 28 days. A diagram of the cell is shown in Fig. 1.

Neutrons were monitored by a single BF_3 counter whose efficiency was approximately 0.35%. The counter was shielded with a 1 mm thick sheet of Cd metal to reduce background and 4 cm of paraffin to thermalize fast neutrons from the cell. X and γ radiation from the cell were monitored using a Ge detector with a thin Be window. The detector was surrounded by approximately 5 cm of paraffin and shielded by 5 to 10 cm of Pb to reduce background. A low energy (X-ray) spectrum was recorded from 10 to 200 keV and a high energy (γ ray) spectrum from 60 keV to 7 MeV. The detector's full-energy peak efficiency was 18 % at 1.33 MeV. The cell and detector layout is shown in Fig. 2.

Results from Pd-D_2O Cell Measurements

The emphasis in our experiments was to search for radiation resulting from the fusion process. We did not perform any precise calorimetric measurements but in the first run the temperature of the electrolyte was monitored. After the current was applied the temperature rose slowly from 20° C to 50° C in about one hour and remained essentially constant during the entire run. No radical temperature excursions or "excess heat" was observed.

All measurements of neutrons, X, and γ radiation were compared with background runs with the cell in place and an unused Pd cathode. The Pd X-rays at 21 and 24 keV were monitored as a signature for charged particle production in the Pd. A search was made for γ rays at 2223 keV from neutron capture in hydrogen (paraffin) and at 596 keV from neutron capture in the Ge detector. The 6257-keV γ ray from the $n + d \rightarrow t + \gamma$ reaction was also monitored. No X or γ radiation above background was observed in either of the runs. The neutron background rate was measured to be 0.63 cts/min. No statistically significant neutron counts above background were observed in either of the runs. We estimate the number of neutrons from fusion to be ≤ 1 n/s thus the upper limit on the fusion rate in our Pd-D_2O cells from neutron counting is $\leq 5 \times 10^{-22}$ fusions/D_2 pair/sec. We thus obtained null results for Pd-D_2O cell fusion at the level claimed by Fleischmann, Pons, and Hawkins.[1] Our measurements, however, are not sensitive enough to test for fusion at the level claimed by Jones et al.[2]

Measurement of D Concentration in Pd Cathodes

A separate experiment was carried out with an arc melted polycrystalline Pd cathodes to measure the concentration of D_2 in the Pd cathode as a function of cell running time. The current density was 0.5 A/cm^2. In each experiment, the cell was run for a given period of time after which the cathode was quickly removed and placed in liquid N_2. The cathode was then transferred to a vacuum furnace and slowly heated to expel the D_2 gas. The mass of the gas was determined by measuring the change in pressure in a collection vessel. The D/Pd atom ratio rose from 0.68 after 30 minutes of cell running to 0.78 after 2 hours to 0.80 after 6 hours. Thus the cathode appears to saturate at D/Pd $\simeq$ 0.8 in a few hours.

EXPERIMENTS WITH Ti-D_2 MIXTURES

Experimental Details

Upon learning of the claims of observation of neutrons in Ti-D_2 mixtures, possibly from cold fusion, by De Ninno et al.,[3] we embarked on a search for neutrons emitted by Ti deuterated at high temperatures and cooled to liquid N_2 temperatures.

The starting material in all of the experiments was 1/16 inch thick Ti sheet metal. Separate experiments were run with samples of 18 g of chips, 16 g of 200 mesh powder, 34 g of 1/8 × 1/8 inch chips, another 17.5 g of chips, and 23 g of shavings. The samples were subjected to a series of heating and cooling cycles in which D_2 gas at a pressure of up to 50 atm was added to the heated Ti to gradually deuterate it. Temperatures as high as 760 °C were used to finally produce TiD_x with $x \leq 1.90$. The D_2 gas was added from a second bulb and the change in pressure noted. The resulting material was then subjected to a number of cycles where it was cooled to liquid N_2 temperature and allowed to warm to room temperature.

Neutron emission from the TiD_x sample was monitored with a BF_3 counter similar to the one used in the Pd-D_2O cell experiment with similar Cd shielding and paraffin moderation. The counting efficiency was approximately 0.28 %. The layout of the cell and BF_3 detector is shown in Fig. 3.

Results from Neutron Counting

The neutron background for the BF_3 counter was measured to be 0.65 counts/min with the counter in position and the cell loaded with Ti at room temperature but without D_2 gas. Neutron counts were recorded in 10 min periods. No neutron counts above background were observed during the temperature cycling or deuteration of the Ti sample. The total running time was 40 days. We estimate the number of neutrons from fusion to be ≤ 1.3 n/sec, thus the upper limit on the fusion rate in our TiD_x sample from neutron counting is 7×10^{-24} fusions/D_2 pair/sec. We therefore failed to observe neutrons at the level of De Ninno et al.[3] Our measurements, however, are not sensitive enough to be compared with the results of the Los Alamos Group presented at this conference.

SEARCH FOR COLD FUSION IN $LaHD_2$

It was recently pointed out by Koonin and Nauenberg[4] that the fusion rate in the H-D molecule is 10^9 times greater than for the D_2 molecule. This suggested that cold fusion might occur in a system with both H and D. The reaction p+d → ^{3}He + γ produces a monoenergetic γ ray of energy 5493 keV. A sample of ~ 4 g of $LaHD_2$ produced at the Ames Laboratory was enclosed in a glass tube and placed against the face of the Ge γ-ray detector used in the Pd-D_2O experiment. Data was accumulated for a period of 24 days. No evidence was observed for the above γ ray and our upper limit on counts in the 5493-keV full energy peak was ≤ 5 counts/day. This corresponds to an upper limit on the p+d fusion rate in the $LaHD_2$ system of 0.9×10^{-24} fusions/p-d pair/sec.

BARRIER PENETRATION CALCULATIONS

Our purpose in this calculation is to explore the phenomenon of cold nuclear fusion on the basis of a simple physical model. In particular, we examine the sensitivity of the fusion rate to the confinement of the hydrogen-like ions involved, and to the combined electrostatic screening effects of the electrons present in the metal. While the model we shall use is not a realistic description of the system, we feel that the effects described here will be present in more realistic models.

To simulate the effects of a lattice, we assume that the two ions are symmetrically placed near the bottom of a harmonic well, and that their relative angular momentum is zero. Thus, they interact with a potential given by

$$V(r) = \frac{1}{2}Kr^2 + \frac{e^{-\lambda r}}{r} , \tag{1}$$

where K is a constant characteristic of the lattice, λ is the inverse of the screening length, and we have used atomic units ($e^2 = m_e = \frac{h}{2\pi} = 1$). Because the system has a large reduced mass and is near room temperature, the ions sit at the minimum, and the energy E of the system is given by the minimum of the potential, located at r_0 ← addition

$$E = \frac{1}{2}Kr_0^2 + \frac{e^{-\lambda r_0}}{r_0} . \tag{2}$$

Results are presented as a function of r_0 and λ with K fixed by the condition $\frac{\partial V}{\partial r}|_{r_0} = 0.$ ← addition

The fusion rate is controlled by the probability that the system tunnels to small enough separations for nuclear interactions to occur. The probability for this is given, in the WKB approximation, by

$$B = exp(-\sqrt{\mu}I(E))\ . \tag{3}$$

where μ is the reduced mass of the system, and

$$I(E) = 2\sqrt{2}\int_{o}^{r_0} dr\sqrt{V(r) - E}\ . \tag{4}$$

The results for $I(E) = -log(B)/\sqrt{\mu}$ for a variety of parameter values are shown in Table I. For purposes of comparison, we note that for diatomic molecules of hydrogen-like atoms in free space the tunneling probability has been estimated to be[4]

$$-\frac{log(B)}{\sqrt{\mu}} = 4.13\ , \tag{5}$$

which translates into 10^{-64}d-d and 10^{-55}p-d fusion reactions per second. Since $B = 10^{-log_{10}(e)\sqrt{\mu}I(E)}$, decreasing $I(E)$ by unity increases the fusion rate by *18 orders of magnitude for d-d and 15 for p-d.* To obtain the fusion rates claimed experimentally would require a decrease of about two units in I(E) from its value of 4.13 in the isolated D_2 molecule.[4] In Table I, we see that this requires either an equilibrium separation of less than half a Bohr radius (a_0), or a screening length significantly less than $0.25a_0$ ($\lambda > 4.0a_0^{-1}$). ← addition ← addition

Whether or not these conditions actually pertain to the systems in question is ultimately a question for more detailed calculations than those presented here. There are, however, several conclusions that may be drawn even at this stage. First, we note that the equilibrium separation of hydrogens in palladium is of the order 2 Å at the stoichiometric limit, indicating that the potential well in which an individual hydrogen sits has a radius of approximately an angstrom. Thus, the equilibrium separations under discussion here are unlikely even with two ions in a single well. Furthermore, we cannot imagine a mechanism for getting two ions in the same well with any appreciable probability. Further discussion of these theoretical fusion rates can be found in Ref. 6.

CONCLUSIONS

We have searched for evidence of cold fusion in Pd-D_2O cells and TiD_x mixtures by measuring neutrons with BF_3 detectors, and X and γ rays with a large volume Ge detector. No neutrons, X, or γ rays above background were observed in any of the experiments. Our measurements were sensitive to cold fusion from Pd-D_2O cells at the Fleischmann, Pons, Hawkins[1] level and to neutrons from a temperature cycled TiD_x system at the level of De Ninno et al.[3] However, we are not sensitive enough to detect neutrons at the level of Jones et al.[2] from Pd-D_2O cells or neutrons from TiD_x systems at the level of the Los Alamos Group.[5] Also no excessive temperature fluctuations were observed in the Pd-D_2O cells.

Our calculations demonstrate that the fusion rate for hydrogen-like ions in a confined system are extremely sensitive to the details of the confining interaction and electrostatic properties of the medium. The fusion rates for PdD_x systems reported in Refs. 1 and 2 are much larger than those predicted by these calculations.

REFERENCES

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2. S. E. Jones, E. P. Palmer, J. B. Czirr, D. L. Decker, G. L. Jensen, T. M. Thorne, S. F. Taylor, and J. Rafelski, Nature, **338**, 737 (1989).
3. A. De Ninno, A. Frattolillo, G. Lollobattista, L. Martinis, M. Martone, L. Mori, S. Podda, and F. Scaramuzzi, submitted to Euro. Phys. Lett.
4. S. E. Koonin and M. Nauenberg, UCSB Preprint, submitted to Nature, April 1989.
5. Proceedings of Workshop on Cold Nuclear Fusion, Santa Fe, New Mexico, May 1989.
6. C. J. Benesh and J. P. Vary, Phys. Rev. C, **40**, R495 (1989).

FIGURE CAPTIONS

Fig. 1. Diagram for the Pd-D_2O cell.

Fig. 2. Layout of Pd-D_2O cell and radiation detectors.

Fig. 3. Layout of Ti-D_2 system and BF_3 neutron detector.

Pd - D_2O CELL DETAIL

corrected

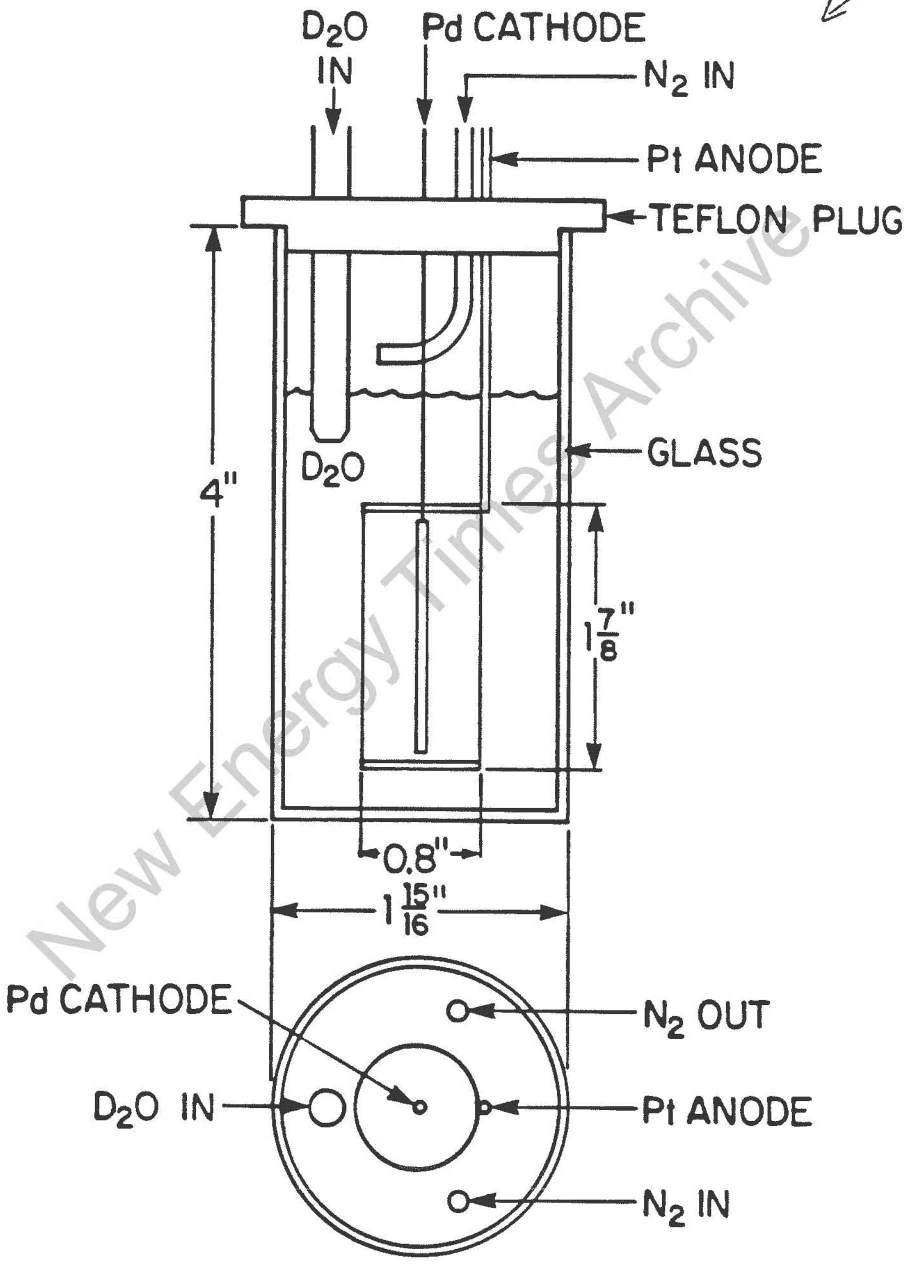

Fig. 1. Diagram for the Pd-D_2O cell.

Pd - D_2O CELL + DETECTORS

(TOP VIEW)

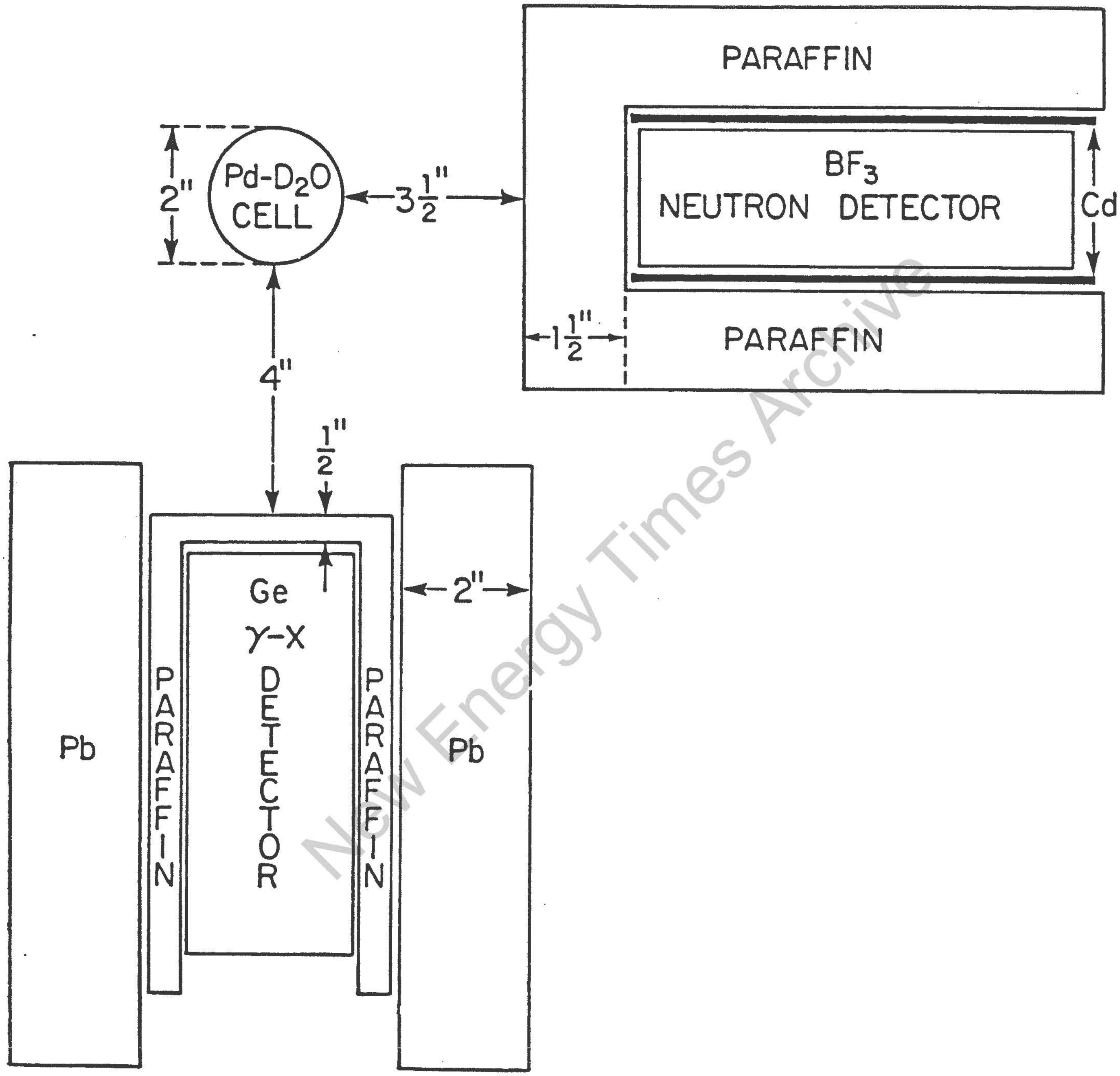

Fig. 2. Layout of Pd-D_2O cell and radiation detectors.

Ti - D CHAMBER + n DETECTOR

(TOP VIEW)

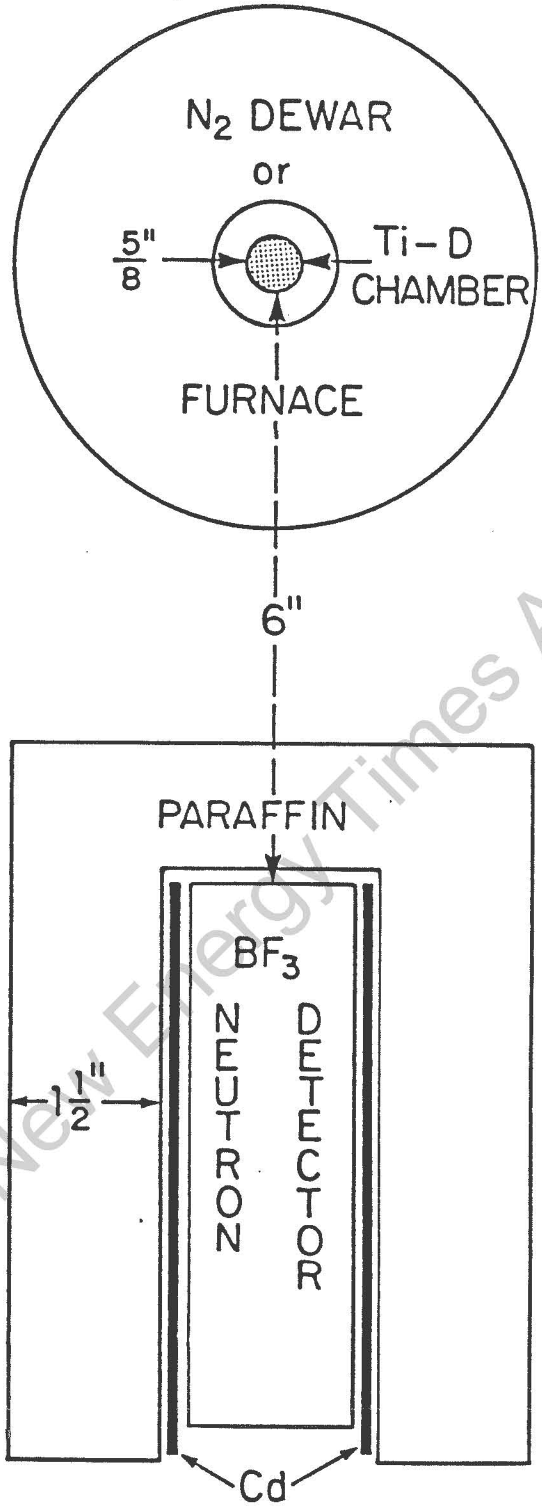

Fig. 3. Layout of Ti-D_2 system and BF_3 neutron detector.

Wed. August 9, 1989

Greetings:

We finally had a moment to call Fed. Express (1-800-238-5355). A lady noted that a T. Walton received our so call minority report that we hope may help your committee on evaluation of "cold" fusion (electrolysis concepts). That was 9:09 AM your Washington time, August 1, 1989.

Since we had to hurry so much with so little time after hearing of your committee, we are ready for any questions of possible clarification needs. Two numbers noted for any message.

DEPT. OF ENERGY
EXECUTIVE SECRETARIAT
89 AUG 14 AM 11:08
012081

Allen J. Bard
DEPARTMENT OF CHEMISTRY
The University of Texas at Austin
Austin, TX 78712

11 SEP 89 13. 65

-R.L. GARWIN-

MEMORANDUM

Date August 29, 1989

To: Bill Woodard

From: Al Bard

Attached is a write-up of some of the points made by Fleischmann at the IUPAC meeting. Could you take care of distributing this to the panel members?

Best wishes.

August 28, 1989

TO: Cold Fusion Panel

FROM: Allen J. Bard

RE: Talk by Martin Fleischmann at IUPAC Congress - Stockholm, August 5, 1989

"Solid State Fusion?"

Professor Martin Fleischmann,
Department of Chemistry,
The University, Southampton SO9 5NH

The background which led to the start of this investigation will be outlined. The major question which we posed was: is it possible to electrochemically compress deuterons, D^+, sufficiently in palladium host lattices to allow significant fusion of these species? Our investigation was based on calorimetric measurements of the release of excess enthalpy, as well as the search for the expected nuclear products, neutrons, tritium and gamma rays. We have found that excess heat is produced but that the level of the nuclear products is much smaller than would correspond to the excess enthalpy. It also now appears that there are bursts in the production of enthalpy and it is likely that the production of neutrons and tritium at least accompanies these bursts.

Our observations have led to considerable controversy. While there is increasing piecemeal confirmation of our findings by various research groups, it is equally true that some research workers are unable to confirm any of these findings.

An assessment of the present situation and of the causes of these disparities will be made.

Summary of talk by Martin Fleischmann given at IUPAC Congress - Stockholm

Introduction

In the introductory portion of his talk, MF emphasized that he and Pons approached the experiments "in the spirit of skepticism." He also presented the concept that electrochemistry was a form of high energy chemistry. As an example, he used the reaction NaCl → Na + 1/2 Cl_2 and pointed out that this was carried out by relatively low applied voltages electrochemically but required a very high temperature, if carried out as a thermochemical reaction.

Review of fundamentals

He then reviewed some of the basic concepts in the electrolysis of D_2O at Pd.

$$D_2O + e \rightarrow D_{ads} + OD^-$$

$$D_{ads} \rightarrow D_{lattice}$$

where "$D_{lattice}$ is an octahedral site and is de facto delocalized." He stated, "It is easy to do the elementary thermodynamics, although all this is a kinetic problem." He then showed the basis of the repeated assertion of the effective pressure of D in Pd of 10^{27} atm (i.e., $0.8\ eV = \mu°_g + [RT/2] \ln P$) "thus can raise the activity of D^+ in the lattice in a way that couldn't be accomplished by external pressure." This suggested a "marginal chance" of producing fusion. He stated that one would expect to see "clusters of tightly bound D either in octahedral or tetrahedral sites or at dislocations or grain boundaries."

Calorimetry

He stated he wanted to "lay a few ghosts to rest" concerning calorimetric measurements, and he quickly reviewed experimental considerations: 50 mL cell, solution well-stirred by gas evolution, axial heating time constant of about 20 s, variation of T measured to ±0.01°, etc. He emphasized that all exposed wire and surfaces were covered with glass to avoid recombination. He then went into detail about a "black box model of calorimetry," which appeared to be the same as the one Stan Pons showed during the visit to Utah. This showed the energy in, $[E_{cell} - (\gamma)1.54]I$, and heat out terms by solution evaporation and boiling, conduction and radiation. He emphasized that this was a complicated business and that "one cannot avoid these factors by changing calorimetric technique." He also stressed that they knew that $\gamma = 1$ (i.e., no recombination of D_2 and O_2).

However, he then went on to show the same calibration procedures that were shown before (e.g., the same T vs. time heating curve shown by Pons at the 12 April ACS meeting) showing the temperature rise of 1.55 °C (From 36.5 to 38.5 °C), etc. There was no new discussion of calibration.

He discussed the calorimetric data. Although MF stated their calorimetric measurements "stretch back over six years," the data he showed appeared to be exactly the same as that in the Pons/F communication and in Pons' April 12 talk, with corrections in several places for various errors. He said that, historically, their measurements went from a Pd cube to sheet to rod. The 1 x 1 x 1 cm cube experiment was apparently one of the early experiments, and he again described the now famous "event" when a "big discontinuity in operating conditions" caused the cube to "melt through the bottom of the Dewar flask." The Pd looked as if "Pd had evaporated", but there was "no untoward radiation about." He said they then started working with sheets and rods. During the measurement of heat, they also measured neutrons, gammas, and tritium "for safety reasons" in "a very rudimentary" way. They knew, however, that the enthalphy release was much larger than accounted for by radiation. They were convinced that "either the results are wrong or it must be a nuclear process."

MF stated that contrary to popular opinion and the statement of the editor of a well-known journal [Nature], they did do blank experiments, "every blank you can think of." Moreover, "when steady state heat is increasing and steady state cell voltage is decreasing, you cannot explain increasing temperature with a decreasing input by chemistry." He then went on to show "temperature burst" data, which appeared to be the same two-day T burst shown at the ECS meeting and during the visit to Utah. He showed one cell, operated at 0.8 A, where the temperature increased and the solution began to boil. In this cell, he claimed, "amounts of heat are phenomenal."

Radiation measurements

He briefly discussed these. He said in measuring tritium "chemiluminescence was not totally suppressed in the sample shown." He felt that the "time dependence of tritium generation is highly irregular" and that "tritium is generated in pulses during temperature pulses." MF felt that they did see neutron emission, that "the only time they saw neutrons was when the cell was generating excess heat and that neutrons come out as bursts as well." He felt that the levels of tritium found by them cannot be explained by separation factors. He also mentioned Bockris' tritium results with Pd/Ni cells. He "urges people to be careful. We had an electrode melt—other people had electrodes melt." MF went on to show the figure from their paper concerning confinement, etc., and defended projections in the paper based on operation in the "fuel cell" arrangement. He feels they are "hovering at the break-even point."

Conclusions

MF felt that the failure of others to reproduce their results resulted from the use of too small electrodes, low current densities, and short electrolysis times, but before he comments in detail on these studies, he wants "to see what appears in publications." MF and SP are "well aware that the system is more complicated than they originally thought and that they were very lucky that they originally got the results they did." They "have not been as successful recently." They "continue to look for the possibility of systematic error." However, he stated there was "absolutely no reason" for them to "change their mind" about the results.

Questions and Answers

Q / Did they compare Na^+ and K^+ electrolytes (in place of Li^+), considering the report of Appleby et al.?

A / No. Their results are "too partial" and he would not like to comment on them "in public".

Q /	Did they try various H/D (H_2O/D_2O) ratios to probe p + d channel?
A /	No. They only used 99.5% D_2O.
Q /	Did they add poisons to solution, to affect surface electrochemistry of Pd?
A /	He first said, "I refuse to answer that question." Then he went on to say that none of the experiments, to his knowledge, involved purposefully added poisons.

During the Q/A period, MF also mentioned that one needs to spend "an enormous amount of time pulsing the electrode between the α- and β-phases to get "bursts" and that they are probably dealing with a threshold phenomenon and need high current density. They are currently developing "heroic calorimetry" to "force the system to more extreme conditions—of course, everything falls to pieces under these conditions."

AJB Comments.

I was struck by the absence of any new results or evidence—all data presented went back to April or May. MF came across as remaining very sure of their results and believing in "solid state fusion." However, in private conversations with him, I detected more reservations.

To: W.L. Woodard, DOE (Via FAX to 9-202-586-3119)

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September 7, 1989

Dr. P.K. Iyengar
Bhabha Atomic Research Centre
Trombay, Bombay 400 085
INDIA

Dear Dr. Iyengar:

I have just read with interest your "Cold Fusion Results in BARC Experiments," presented in Karlsruhe July 3-6, 1989. I write as a member of the United States Department of Energy Cold Fusion Advisory Panel which is in the process of preparing a final report to the Secretary of Energy, due 11/15/89.

In this field, there are many experiments of excellent quality that give negative results-- no neutrons, no tritium above that present in the feed heavy water, no protons, and no heat. Of course, the measurement of particles produced is far more sensitive than the measurement of heat. I visited Frascati 06/09/89, and I have since talked with Ugo Valbusa, who gave me information I reported as follows:

> At a Pugwash meeting, 07/27/89, I met:
>
> Dr. Ugo Valbusa
> Dipartimento di Fisica
> Via Dodecaneso 33
> 16136 Genova
> ITALY
> W: (39-10) 5993; x261 Office;
> x246 Secretary; x356 Lab.
>
> Valbusa is a solid state physicist who has been working with nuclear physicists in order to investigate cold nuclear fusion. At first they obtained seemingly positive results from D2 + Ti, using a system in which plastic scintillator was interspersed with Cd foil. Phototubes looking at the collection would see initially from a fast neutron the proton recoil, and then tens of microseconds later, another pulse which would be from the capture gamma rays in the Cd.

> Small containers of 2-3 cc volume were immersed in the plastic scintillator, and counts were obtained on warming from nitrogen temperature.
>
> A "blank experiment" was performed, with H2 instead of D2, and no counts were seen!
>
> They were about to publish.
>
> Then they tried empty containers, and they saw counts again.
>
> They have discovered that if one puts a thermal gradient across the plastic scintillator, one gets counts!
>
> They have now modified the system to use liquid scintillator instead of plastic, and a vacuum to isolate the Ti cell from the scintillator. This experiment will start soon.
>
> In another experiment, they used Indium foil around the cell, inside a moderator. The idea was that neutron emission would activate the Indium, which could be counted in an ordinary counter later.
>
> This is not so sensitive an experiment, but there is no possibility of confusion with thermal gradients, and the like. Their result is that they see fewer than 50 neutrons per second. That is, they see no neutrons above background, and their sensitivity is 50 neutrons per second.
>
> Interestingly enough, Valbusa gave me word of the group at Cassacia, on which I have reported previously. Their experiment was to degas Ti at 1000 C, then to cool it to room temperature or to 500 C, and to contact it with 20 torr of D2. As you recall, they saw declining numbers of counts, of the order of 700 counts per minute for 5 minutes or 3000 counts per minute for 5 minutes in different trials.
>
> However, the Cassacia group has now discovered that the problem is due to a difficulty in their BF3 counter! They have no positive result.
>
> Science marches on!

Among the papers reporting positive results, your Karlsruhe presentation provides the most information for the reader. Furthermore, Table I is most impressive, in that small cells and large cells with very different electrolytes and cathode materials provide tritium levels increasing by a factor ranging from 500 to 20,000.

I am very anxious to learn the present state of this work and of the publication of the "Consolidated BARC Report" to which you refer in your last paragraph. However, I have one question of consistency. In the ABSTRACT and in para. 6(a), you emphasized that the ratio of neutrons produced to tritium produced is less than 10**-8. In 6(b) you ask the important question whether the neutrons are primary or whether they are produced in a

> "secondary reaction involving the energetic protons or tritons. In this context it would be of interest to look for the possible presence of 14-MeV neutrons in cold fusion experiments."

Of course, several groups have looked for the "energetic protons" that would accompany the tritons, but have found none. Nor have they found the Coulomb excitation gamma rays that would be produced by such energetic protons in Pd.

But I have a specific question. If the tritium is produced in the normal d-d reaction (with the competing neutron branch totally suppressed somehow), it is born with a kinetic energy of 1 MeV. One of the most convenient ways of making neutrons in the laboratory is to have a beam of tritons of energy even substantially less than 1 MeV incident upon a Pd-d or Ti-d target, and this produces far more than 10**-8 neutrons per incident triton. Even if the tritium is produced at the very surface of the cathode, half of the energetic tritons will be directed into the Pd-d interior and should give rise to copious production of 14-MeV neutrons. What are the experimental results at BARC about the number of neutrons total compared with the number of tritons, and the number of 14-MeV neutrons?

I am worried about the inconsistency between the large amount of tritium routinely produced by the various groups at BARC and the 10**-8 smaller number of neutrons.

If you could respond to me by Telex as given above, I would be most grateful. If you have a FAX at BARC, I would be grateful also for its number, and you can use the FAX number given above.

If you have a report that you can make available to me (which would be of great interest to the other members of our Panel), please so indicate, and I will let you know how to send it to me by Express Service at my expense.

Thank you very much, and thank you also for the very interesting paper.

Sincerely yours,

Richard L. Garwin

cc:
P.K. Iyengar, (Via TELEX to 953-117-3378)
W.L. Woodard, DOE (Via FAX to 9-202-586-3119)

RLG:jah:250%PKI:090789.PKI

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September 5, 1989
(Via Airborne Express)

Dr. William L. Woodard
Cold Fusion Panel Secretary
Energy Research Advisory Board
to the
United States Department of Energy
1000 Independence Avenue, S.W.
Washington, DC 20585

Dear Bill,

I write primarily to enclose COLD FUSION NEWS No. 19 by D.R.O. Morrison. Would you please see that this is distributed to the Panel.

For your information, I have received no response to my letter of 08/16/89 to Professors Fleishmann and Pons; you distributed this to the Cold Fusion Panel with your note of 08/21/89.

Incidentally, as far as the appendix to our Panel report is concerned, it should list my visit of 06/09/89 to Frascati (Rome), Italy.

I have read the paper by P.K. Iyengar, Cold Fusion Results in BARC Experiments, which you distributed 08/28/89. I want to comment only on the stated branching ratio of "less than 10**-8" between the neutron branch and the proton branch of the d + d reaction. On this remark, I need quantitative support from Koonin or Schiffer. The problem, of course, is that d + d produces tritium of 1 MeV, accompanied by a proton of 3 MeV. If you refer to page 9 of COLD FUSION NEWS No. 19, you see Morrison arguing that the 3 MeV protons would give large numbers of neutrons from the charge exchange reaction p + n = n + p, but as indicated in my enclosed letter to Etienne Roth the protons actually have insufficient energy to produce neutrons from deuterons in this way. The problem is that the p + n is bound in a deuteron with 2.2 MeV energy, but p + p product state (after charge exchange) is not bound.

Also Adjunct Professor of Physics at Columbia University
(Views not necessarily those of IBM or Columbia)

On the other hand, the 1 MeV tritons as they slow down certainly will cause a very substantial yield of 14 MeV neutrons from the d in the cathode. Note that this would be the case whether the tritium is produced on the surface or in the interior of the cathode, since the tritium nuclei directed into the bulk would cause this reaction. It seems to me that the yield would be more like 10**-5 than 10**-8, which indicates to me that wherever the BARC tritium comes from, it is not d + d reaction. Note that this is true even if (especially if) the fusion took place in moments of hot fusion, during the disruption of the material as hydrogen was introduced.

I will try to contact P.K. Iyengar at the Bhabha Atomic Research Centre for more information, but I don't guarantee results.

Finally, I enclose a paper I received from Dr. Michael Danos. Perhaps you already have it. Here is also a copy of a question I sent him, and his reply just received.

Sincerely yours,

Richard L. Garwin

Richard L. Garwin

Encl:
- 08/25/89 COLD FUSION NEWS No. 19 by D.R.O. Morrison. (082589DROM)
- 07/18/89 LTR RLG to E. Roth re branching ratio in fusion. (071889..ER)
- 07/24/89 LTR M. Danos to RLG re "Coulomb Assisted Cold Fusion in Solids." (072489..MD)
- 08/11/89 LTR RLG to M. Danos. (081189..MD)
- 08/21/89 LTR M. Danos to RLG. (082189..MD)

RLG:jtml:248%WLW:090589.WLW

(3.1)

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  01 Sep 89 00:28:50 GVA
 Received: from mint.cern by CEARN.cern.ch (IBM VM SMTP R1.2.1) with TCP; Mon, 09
  Jan 89 00:28:35 GVA
 Received: from cernvax.uucp (cernvax) by mint.cern (cernvax) (4.12/3.14)

id AA04925; Fri, 1 Sep 89 00:29:07 +0200
 Received: by cernvax.uucp (5.57/Ultrix2.0-B)

id AA04040; Fri, 1 Sep 89 00:19:21 +0200
 Message-Id: <8908312219.AA04040@cernvax.uucp>
 Date: Fri, 1 Sep 89 00:17 GMT +1
 From: MORRISON%VXPRIX.decnet.cern.ch@cernvax
 To: rlg2@yktvmv
 X-Vms-To: MINT::"rlg2@yktvmv"
```

Dear E632 and WA84 Colleagues, 25 August 1989.

COLD FUSION NEWS No. 19

Cold Fusion Heats Up! New Institutes Founded.

1. Summary

2. Starting up of National Cold Fusion Institute for Research
    2.1 Introduction
    2.2 Procedings and Vote of Advisory Board
    2.3 Funding
    2.4 EPRI meeting to discuss positive results

3. Starting up of BYU Fusion Research Centre

4. Starting up of Japanese Institute of Fusion Science

5. Building of Giant Fusion Cell in India

6. Utah Reports no Neutrons or Gammas from Pons's Cells

7. Discussion of Positive results
    7.1 Florida Results Contested - Upstairs/Downstairs
    7.2 Checks of Texas A&M Tritium Results
    7.3 General Electric
    7.4 Other Positive results
    7.5 Summary of Positive and Negative Results.

8. Other Items
    8.1 Visit to Harwell
    8.2 Report from Berlin
    8.3 Comments on DOE Panel Report by Dr. Pons and Senator Garn.
    8.4 Paper from Madrid
    8.5 Changes at Los Alamos
    8.6 European Physical Society
    8.7 High Altitude Cold Fusion

Notes on LEP

082589DROM

1. SUMMARY

The last week has been rather wild and quite fascinating.

It might be thought that the recommendation of the Interim report of the DOE Panel on Cold Fusion "against any significant expenditures to establish cold fusion research centres" might have some effect. But the State of Utah has now set up the National Cold Fusion Research Institute after its Advisory Board appeared to have heard only positive testimony. Strong additional funding is expected from industry. Neighbouring BYU does not seem to have been involved, but they have now established their own Fusion Research Centre!

The menace of Japan taking over a great American discovery has been brandished. Now it is reported that a Japanese Institute of Fusion Science is being organised. Also in India a five foot tall cathode is being built which would be bigger than any other.

Then yesterday there was quite a bit of excitement in Utah when Mike Salamon gave a press conference to announce their results (see No.18), that their neutrons and gamma counters see no fusion from the cells in Dr. Pons's lab. The response of Dr. Pons was breath-taking (section 6).

Much of the justification of the Utah State Advisory Board came from the positive results obtained in Florida and at Texas A&M. However the Florida results are contested by a group upstairs(section 7.1) and the lack of checks for the Texas results are discussed in Section 7.2. Finally all positive and negative results are briefly summarised in Section 7.5

Comments from Utah (and elsewhere) on the DOE panel report are fine examples of contemporary politics and worth savouring (section 8.3).

2. STARTING UP OF NATIONAL COLD FUSION RESEARCH INSTITUTE

2.1 Introduction

A major new Research Institute has been set up which is intended to be National, not for the State of Utah only. The funding is expected to be national also. How this came about despite the recommendations of a federal panel, is a classic case worthy of study by students of Science Politics and of Life. The essential seems to be to reinforce the positive and exclude the negative - peer review is excluded.

2.2 Procedings and Vote of Advisory Board

The Utah State Advisory board on Energy/Fusion held hearings to establish whether the original claims of Profs Fleischmann and Pons were confirmed. All accounts agree that only positive results were presented. As they appeared impressive, it is only fair to the board members if we give them.

B. Stanley Pons told the Board that he had used "Cold Fusion" to boil water and suggested that household uses for his purported discovery were in the offing. In his experiment a "boiler" the size of a thermos emmitted 15 to 20 times the amount of heat being put into it -- a reaction that cannot be explained by normal chemical reactions, Dr. Pons said (Rayleigh Times and Observer, July 12). On the other hand it was said by GE that Drs. Pons and Fleischmann have admitted that their early data on gamma ray spectroscopy was flawed. It was said the results were " inappropriately homogenised" (SLC Tribune).

A report from the U. to the state Energy/Fusion Advisory Council was leaked to the Salt Lake City Tribune. It lists the "silent" organisations that have obtained confirmation of Fleischmann and Pons's work but have not published.

It said that scientists at the General Electric Company's "research facility at Schenectady, NY had reproduced the experiment and have 'obtained excess energy at about the 15% level'. The report also says that GE 'after long and careful study..... concludes that the basic calorimetric theory of Pons and Fleischmann is correct and shows excess energy'. GE refused to confirm the report. 'We're not confirming or disclaiming heat', said Peter Van Avery, GE's manager of communications [an interesting title - does it mean manager of telecommunications or of public relations? - my comments are in square brackets] at Schenectady. 'We're not making any claims at all, but the research is continuing.'"

" A scientist from GE also examined the research of (U College of Mines Dean)

Dr. Wadsworth, the report said. 'The GE thermodynamist concluded that those data cannot be explained by any error in measurement, nor any chemical phenomenon'"

The Deseret News later said that "The GE scientists also have reported finding significant levels of tritium in the electrolyte, but no signs of helium 4 in the bar".

"The report also said Edmund Storms and Carol Talcott of Los Alamos National Laboratory have electrochemical cells that produced excess heat 'after being coated with a lithium-palladium alloy'" [probably it was the electrodes that were coated].

"Drs. Storms and Talcott had earlier reported the production of tritium, a fusion by-product, in the same cells. Both researchers were unavailable for comment Tuesday".

"Charles D. Scott of Oak Ridge National Lab. has one cell that is showing 'small excess of heat(about 8%)', the report said. Dr. Scott was not in his office Tuesday afternoon, but Oak Ridge spokesman Ed Aebischer said 'He has apparently seen some evidence of heat production'. Mr. Aebischer added that the results were preliminary".

"More confirmation of heat was attributed to Michael Mackubre, a researcher at the Stanford Research Institute in Menlo Park, California. 'He has had several incidents of extended excess heating', the report said"

"The report said Dr. Mackubre used closed system calorimetry. Some critics of the U. research have said that a closed system, where none of the evolving gases is allowed to escape the cell, is more accurate than the open system used by Dr. Pons and the others who have reported the heat."

"Dr. Mackubre was unavailable but the results were acknowledged by a representative of for the Electrical Power Research Institute, which is funding the research."

"'That is correct', said John Maulbetsch, senior adviser in the office of exploratory research at EPRI. EPRI is a non-profit research consortium funded by electrical utility companies. 'There have been some indications of heat, but they have been sporadic'."

"And another scientist at Case Western Reserve University reported'low levels of excess energy'. The researcher was identified only as E. Yeager."

"The report also made reference to instances of tritium production by Thomas Furtek at the University of Colorado. Tritium has been reported by a number of laboratories, but it has come in levels far below the excess heat."

The U student newspaper, the Summer Chronicle, reports some of the testimony of Drs Pons and Huggins."Pons said one cell he has been experimenting with produced as much as 22 Watts of continuous power. 'Any reasonable engineer would be able to upscale (the experiment) for commercial use', Pons said. For example, the first commercial product will most likely be a typical water heater for a family home."

He said they would be submitting two papers in the next few months [elsewhere it is suggested that the first will be in September but in talking to Martin Fleischmann yesterday, he described to me so many calculations and other work that he would like in the paper, that it could take longer to write and to review]. "The first paper will detail the calorimetric measurements of the experiment and will present error limits for each calculation." It will perhaps be submitted to the Journal of Electroanalytical Chemistry [it will be interesting to see if it is reviewed the same way as their first paper which was strongly criticised - for example it is the first paper on calorimetry that I have seen that did not give a single temperature]. "The second will analyze the compound tritium which has been detected in small amounts. Pons said tritium is not found naturally and is only present after a nuclear reaction."

"Huggins said his fusion experiments have also produced excess heat and critics of the U experiment are not performing the thermal measurements correctly. 'At Stanford we have four sets of cells operating and each one has given off heat. But the heat from the experiments is giving very sporadic results. This shows that there are still a lot of questions to be answered' Huggins said."

On 21 July the Fusion/Energy Advisory Council voted unanimously to accept the work of B. Stanley Pons and Martin Fleischmann as confirmed. In view of the evidence presented above to the Council and the absence of any report of all the other experiments which found no effect, it was reasonable for the council to vote this way. However the Salt Lake Tribune noted that "it withheld approval of budget specifics because of concern over administrative costs".

"The fusion council's executive committee expedited its approval.... upon learning that the fusion race was gaining speed - particularly at the University of Florida where the most favourable confirmation of the U experiment was recently announced. Southern scientists said Gamma rays, tritium, and excess heat sufficient to light a light bulb, have been produced" (Deseret News).

On 7 August the state council voted to release $4.5 million for research into cold fusion and this allows the funding of a National Cold Fusion Institute for Research. The vote was 7 to 1 plus one abstention - he was Wilford Hansen, the only physicist on the panel, who had caused some controversy by staying on the the panel although at the last moment he had applied for $750 000 of this money for his research. The negative vote was believed to be Dr. Karen Morse who is Dr. Hansen's Provost at USU who was particularly worried about the high administative costs. These two are the only scientists on the panel.

State officials said that this money represents one-third of the State's annual investment in economic development (Deseret News).

U officials said the initial staff will be composed of U faculty members supplemented by interested faculty from Utah State University, BYU, and visiting researchers from other universities and industrial labs. A permanent staff will be developed as quickly as funding levels and the recruiting process permits (Deseret News).

Someone who has studied the State bill to fund the research says that it is carefully written so that funding could be given even though the effect is not fusion.

2.3 Funding of The National Institute

A 25 000 square foot facility has been taken over in the University's Research Park and apparently the first employees were hired some time ago. There is a five year funding plan. Of the $4.5 million voted by the Utah State legislature, between $2.8 million (75% of the Institute's budget) will be spent the first year and the remaining $1.7 m (37%) in the following year. This is regarded as seed money and it is expected that a further $20 million will be forthcoming from industry and government sources. Dr. Pons has said that he will not be joining the Institute as he wishes to concentrate on experiments he should do and wants to do. Some Council members were worried that Drs Pons and Fleischmann would not be adequately funded but Dr. Brophy said "Dr. Pons will get whatever he wants" (Deseret News). He has received funding from the Office of Naval Research (SL Tribune).

The Electrical Power Research Institute, EPRI, is a group sponsored by many members of the electrical power industry. Its leaders and members appear to be believers in the production of excess heat, though they are cautious about other claims. While it is expected that government agencies will fund, this will take some time; the EPRI will fund fairly rapidly, in a few months. The local power utility, Utah Power and Light, is not a member of EPRI, though they follow cold fusion - but they look at ALL the data, both positive and negative.

The Deseret News of 8 August reported that GE has signed a financial agreement to develop fusion research. U. President Chase Peterson said that GE's investment would be "sizable". Dr. James Brophy told the Council that additional corporate funding, likely to include Westinghouse, is being sought and eventually funding from the DOE is anticipated. In this connection, Robert L. Park of the APS reports that Rep. Wayne Owens (R-UT) whose district includes the U, recently sent a "Dear Colleague" letter to fellow members of Congress, urging them to keep an open mind on cold fusion in spite of the negative report of the DOE cold fusion panel.

It is expected that ONR and NSF will fund but mildly.

2.4 EPRI Meeting to discuss positive results.

Yet another meeting has been held at which results and experimenters were selected. Only positive results on cold fusion were given. Dr. Bockris of Texas A&M told me that it was a most impressive meeting. The results from Florida are the most advanced in respect of the fact that they have heat, tritium, neutrons and gamma rays.

He considers there are distinct "types of heat emission;

(1) For most of the time the electrodes do nothing

(2) For maybe a quarter of the time.....they emit a low-level heat .... 10 to 15% excess heat.

(3) What is really exciting is that from time to time the electrodes emit heat which is often 3 to 4 times and sometimes 7 to 8 times, the energy being put in. These bursts last anywhere between 10 minutes to 90 hours. Many of them last 10 to 15 hours. They stop as suddenly as they have begun."

For tritium, he says that 7 or 8 labs have it now though 2 government labs will not announce until they get reproducibility. At Texas they have tried 12 electrodes now and get tritium in large amounts from all of them, but the curious thing is that you never know when it will start - between 7 days and 10 weeks.

The argument as to whether it is a volume or a surface effect continues. Prof Bockris considers that there "are two parties now;

(a) The Fleischmann-Pons party which thinks everything is compressed inside the electrode

(b) The Bockris party which believes that things happen because of very high fields at dendritic tips on the surface."

It would be good to have some solid experimental evidence to justify these two opinions.

Hear rumours that there may be other meetings organised at which only positive results and not all results, will be presented.

3. STARTING UP OF BYU FUSION RESEARCH CENTRE

Not everyone in Utah agreed with the setting up of a National Fusion Research Institute in Utah. When Stephen Jones of Brigham Young University was interviewed for local news on channel 2, he said that he "respectfully" disagreed with the findings of the committee. "We have input that would be useful to the committee", he said. However the Y News, a paper of BYU, on 11 August wrote that "A Center for Cold Nuclear Fusion Studies has been established on campus with B. Kent Harrison, professor of physics as director. Stan L. Albrecht BYU academic vice-President and associate provost said the centre will conduct research on a wide range of fusion-related projects, expanding on the work of Stephen E. Jones and his associates who have been conducting cold nuclear fusion research at BYU since 1986."

"Jones, an associate professor of physics and Douglas N. Bunion, a professor of chemical engineering and chairman of that department, will serve as Associate Directors of the center."

"Harrison said the centre will facilitate the scholarly exchange of information in peer-reviewed journals and at professional meetings and will correlate fusion research at BYU and with other organisations. He said the centre will also attract funding in support of research and develop commercial applications for cold nuclear fusion."

It may be seen that these two centres in Utah have quite different styles.

4. STARTING UP OF A JAPANESE INSTITUTE FOR FUSION RESEARCH
+ 5. BUILDING OF A GIANT FUSION CELL IN INDIA

Have heard some reports of a centre being set up in Japan. The fullest account is in the Salt Lake Tribune of August 24;

"The editor of an Asian science and technology journal said Wednesday that scientists in Japan have organized an Institute of Fusion Science and are rapidly moving ahead in cold fusion.

"Japan is the most organized of all the countries," said Ramtanu Maitra, editor of Fusion Asia, a journal of energy and other technology issues published in New Delhi.

Mr. Maitra was in Utah to see fusion scientists at the University of Utah and Brigham Young University. He met with BYU physicist Paul Palmer Tuesday and with U. of U. College of Mines Dean Milton Wadsworth and National Cold Fusion Institute Director, Hugo Rossi, Wednesday.

Mr. Maitra has a master's degree in nuclear physics from the State University of New York at Stonybrook, but he said he came to Utah as a scientific journalist, not a nuclear scientist. Mr. Maitra said the institute was set up Aug. 1, and some 80 scientists will join under the leadership of Hideo Ikegami, a respected scientist.

He said the Japanese are very cautious and would not embark on such a thing unless it was worth pursuing. "They have found something. It's very clear."

University of Utah officials, in their bid for fusion funding, have repeatedly raised the specter of Japanese scientists using an organized effort to commercially exploit cold fusion before the United States.

He also said the Japanese tend to take a long-term approach to their research. "They won't get very euphoric, but they won't get very discouraged either....You have to get out of the mind-set that if it doesn't happen fast, it doesn't happen at all.

"We have to remember that Japan has an advanced hot-fusion research base," Mr. Maitra said. "This is not something totally new for them."

The Japanese have been closed-mouthed about fusion, he said. It's very difficult to get information...

But he believes they will eventually be willing to publish more on fusion than their U.S. counterparts, who tend to classify such research for national security or patent reasons.

Mr. Maitra also said his own country, India, has stepped up its cold-fusion efforts at the country's nuclear research centers, including the Trombay Nuclear Research Center. Trombay, about 20 miles from Bombay, has 12,000 scientists [surely an error - it should be "staff" not "scientists"], he said.

One Indian group has build a five-foot-tall cathode for a cold-fusion cell, which far exceeds anything built in the United States. "They wouldn't have gone for it if they were't seeing anything significant," he said.

He said Asian scientists are acutely aware that cold-fusion research was launched in Utah, and several of them expressed envy that he was visiting here."

Have minimal confirmation of what Mr. Maitra has said and would welcome any completely independent confirmation. In the early days there were reports of work on cold fusion in Japan and Tokyo and Hokkaido Universities were reported as confirming some effects, but since then there have been remarkably few reports. Maybe as Sherlock Holmes said in the Hound of the Baskervilles, the real question is why the hound did NOT bark.

In India three labs have reported results which could be considered positive confirmation. Dr. P. K. Iyengar, Director of the Bhabba Atomic Research Centre at Trombay, Bombay, has sent me a paper "Cold Fusion in BARC Experiments" where he reviews a series of positive results obtained by groups at his institute. He says that full papers are being prepared and one looks forward to receiving them.

6. UTAH REPORTS NO NEUTRONS OR GAMMAS FROM PONS'S CELLS

In the previous note, No. 18, it was explained that while several of Pons's cells were running on a table in his lab, Mike Salamon, Ed Wrenn and Haven Bergeson and Collaborators were operating neutron and gamma counters underneath the same table. No fusion products were detected.

On 24 August Drs Salamon and Bergeson went public with their results which caused considerable local interest. They have written a paper for Nature. Their main result are;

a) the upper limit for neutrons corresponds to less than one billionth of a Watt from the reaction $d + d \longrightarrow {}^3He + n$

b) the upper limit for gammas corresponds to less than one billionth of a Watt from the reaction $d + d \longrightarrow {}^4He + \text{gamma}$

c) the upper limit for internal conversion electrons is about one billionth of a Watt - these would be the E2 nuclear gammas from Coulomb excitation of the even-even Pd isotopes by the 3 MeV protons produced in the reaction $d + d \longrightarrow t + p$

These would seem to cover the main fusion reactions.

These results would appear to exclude the helium internal conversion theory of Chaves Walling and John Simmons. And what is important today, be in contradiction with the results reported on tritium production. It would be good if it were possible for a group finding tritium were to co-operate with the Utah group to make simultaneous measurements as a single measurement of a surprising result needs confirmation by a simultaneous measurement of a different nature, to be generally acceptable.

Neither physicist was willing to dismiss Pons and Fleischmann's results but they said it would require a mechanism unknown in nuclear physics.

According to a previous agreement they showed their paper first to prof. Pons. His answer was very simple - in the six weeks in May and June when they were running, there had been no heat excursions. The Salt Lake Tribune quoted;

"'I'm not at all surprised by their results' said Dr. Pons, who said the cells they were monitoring were running at barely detectable levels. Dr. Pons said the cells had none of the heat 'bursts' that have been reported. These bursts have produced up to 50 times the energy supplied by the cells battery, Dr. Pons has reported, but they have been extremely elusive."

"'We have purposely kept the power amounts low on these cells', Dr. Pons said, explaining that he and colleague Martin Fleischann are trying to 'lower our error bars' in their heat detection."

All this is rather strange. In his previous report in No. 18, it was written "During this period we were informed at least twice that there was at least one "active" cell; during one of these times, the D2O electrolyte was personally observed to be boiling. Our discussion focusses on the episode, which lasted approximately two hours until the cell was turned off under Prof. Pons's instructions -- this was to avoid a catastrophic event.". Also Dr.Pons's group tried to generate cell activity for them by changing the current suddenly from 100 mA to 600 mA in the most promising cell (the one that boiled later). There seems a contradiction here. However it could easily be resolved by looking at the original log books kept by Pons's group. From past history, it is possible that the reply will be given that the lawyers will not allow it. This would be a surprising reply since Dr. Salamon has measured one billionth of a Watt which could be of no practical importance to a lawyer. However the argument might still be employed, so it is to be hoped that the pages will copied and stored separately and carefully to avoid any unfortunate accidental erasing of such historically important data.

The Tribune continues "Despite their null result in Dr. Pons's lab, Dr. Salamon and Dr. Bergeson are setting up a lab at the National Cold Fusion Institute. The scientists say they will not be operating any fusion cells themselves but they will be assisting others in looking for fusion particles." So far as I can make out the Institute will run almost as a funding agency with various groups being semi-independent. Thus Dr. Salamon will be a group which will be called on whenever another group finds a heat excess and his group will make independent measurements, usually of different fusion products. This seems an excellent procedure - and I hope my understanding is correct!

It strains one's belief that during the six weeks in May and June that Dr. Pons did not once wish to do a test which made a cell active, especially when he knew that his colleagues were making a test during these six weeks. However if we assume it were true, then Dr. Pons has just said "we purposely kept the power amounts low on those cells". Now "keeping low" normally means that the power was not zero. What is the smallest possible power that Dr. Pons could measure? Certainly more than a one milliwatt (this surely will be given in their forthcoming paper). Now at a milliwatt of power from fusion, this would imply a flux of over a billion neutrons per second. Since this enormous signal was not observed, then from the results of Dr Salamon et al. and the statement of Dr. Pons, it must be concluded that the heat they observe cannot originate from nuclear fusion".

7 DISCUSSSION OF POSITIVE RESULTS REPORTED.

7.1 Florida results contested. Upstairs/Downstairs.

In May I heard that at the University of Florida in Gainsville, evidence had been found for tritium in cells. However I then heard that there were two groups working in the Nuclear Science building.

It was the Downstairs group of G. Schoessow and J. A. Wethington, both Emeritus professors of Nuclear Engineering, who had held a press conference to announce the observation of tritium in their one cell which had been running for a few days.

The Upstairs group consisted of 9 people, who are a mixed team of nuclear chemists, electrochemists, condensed matter physicists and nuclear physicists. They had been running much longer and studying calorimetry, neutrons. gammas and tritium. They did not find any effect. They also pointed out that the Downstairs group were working with heavy water that was heavily contaminated with tritium.

Felt that this affair was closed so commented very little about it.

However on 4 August on the KUER radio fusion update programme of NPR, Prof. Schoessow said that they claimed to see tritium. In the CNF summary part 1, version 2 is written "After 48 electrolysis, they find about 1 E9 tritons. After 100 hours, they find about 2 E10 tritons. A control run without current produced negligible tritium. They subjected the the Pd to a 'special treatment' before the experiment but are uncertain which 'adaptation may have contributed to
their findings.'"

" On the radio he said that he has a cold fusion cell of his own design, patent pending. He claims he can vary the heat output continuously, and on demand, from no excess heat to 200% of the input energy. He has measured tritium at a rate of 50 000 disintegrations per minute per ml of electrolyte. He said he has deliberately not said much about his work. He did not want it to leak out before he was sure of his results. His university had asked him not to speak to the press, but he had granted an interview to NPR before the request was made. He went on to say he had been called by many companies that are trying to get a cold fusion cell working. He said they often have 20 or more cells running and cannot get any effect.

Prof. Bockris has been reporting to me that the observations of tritium at Florida confirm their own work in Texas A&M. He feels they are the most advanced series as they have heat, tritium, neutrons and gamma rays. He says he is most impressed by them especially as they are respectively 81 and 75 years old (though still younger than Lineus Pauling who had a paper on Cold Fusion published in Nature at the age of 88 years). The results of the Downstairs group have apparently made a great impression in Utah and greatly helped the new National Cold Fusion Institute. Prof. Bockris says he is going to visit them these days.

I have sent a message to them asking for copies of their results as it is not possible to judge from the indirect messages I have received.

The Upstairs group have continued their measurements with one to three cells. They find no evidence for cold fusion and therefore do not endorse the claims of Drs. Schoessow and Wethington. In particular their methods are different.

The situation seems unclear but since they are neighbours it should be possible to arrange for an internal workshop to discuss exhaustively the two sets of experiments. Naturally I am sure that in these circumstances it would be best for the reputation of the Department, if there were no publications, press releases or TV interviews.

PS This evening, 30 August, received a message that the Upstairs group leader, Dr. Muga and Dr Achey have talked with professors Schoessow and Wethington who said that they only claimed excess heat and they did not claim particles or tritium. When asked specifically about tritium, Prof. Schoessow replied "We do not want to see tritium".

7.2 The Texas A&M Tritium Results

Prof. Bockris sent me the preprint of their paper "Production of Tritium from D20 Electrolysis at a Palladium Cathode" by N. J. C Packham et al. which they had submitted to Nature but the referees reports were unsympathetic. He asked for my opinion. The paper reports on 24 cells tried. Results of measurements for tritium for nine of them are tabulated for a variety of running conditions and activities up to 5 E7 disintegrations per minute per ml were given. These are very high rates and my immediate concern was for the health of the experimenters. If the tritium was from the reaction

$$d + d \longrightarrow t + p$$

then the 3 MeV protons would give large numbers of neutrons from the charge exchange reaction, $p + n \longrightarrow n + p$, and the 1 MeV tritons would produce neutrons from $t + d \longrightarrow n + {}^4He$. A serious biohazard.

There were checks that the initial materials did not contain tritium, but the obvious check that has been many times discussed (e.g. Nature) to repeat the measurements with ordinary water, H20, had not been done. Also the check where the cathode was replaced by an inert material such as platinium had not been done. As a fairly experienced referee and editor, this was sufficient grounds for asking for further work as when one claims an important result, normal standards of refereeing should apply. In addition the paper was not up to normal standards in several other respects.

7.3 General Electric

It was written in a confidential report that was obtained by the SL Tribune, that GE personel had found 15% excess heat. However in a radio interview, Hugo Rossi, the new Director of the National Cold Fusion Institute explained that he had written the letter himself to the Council. He said that the GE scientists had been given three P&F type cells prepared in Pons's own lab, one of which (according to P&F's measurements) consistently produced 15% excess heat. The three cells were taken back to Schenectady for GE scientists to make their own measurements. There was evidently some question in the minds of the GE people over the calibration and Rossi stated that if a conservative view was taken, the 15% would evaporate. Rossi made it clear that GE scientists had not confirmed excess heat.

7.4 Other Positive Results

7.4.1,2,3 The three positive results that most impressed people at the EPRI meeting were from Florida, Texas and GE and they have been discussed above. About the other quoted results;

7.4.4 Utah - see measurements of Salamon et al. discussed earlier.

7.4.5 Drs Storms and Talcott at Los Alamos National Lab. The Lab has called these results preliminary. It is said that after the first two cells subsequent cells (60 of them!) had failed to show an effect.

7.4.6 Dr. Scott of Oak Ridge National Lab - the Lab spokesman called these results "preliminary"

7.4.7 Dr. Mackubre of Stanford Research Institute has claimed 8% excess heat. The EPRI funding agency described them as "some indications of heat, but they have been sporadic". More information is necesary.

7.4.8 At Case Western Reserve University, "low levels of excess energy" have been reported - more information is necessary.

7.4.9 Tritium production at the University of Colorado at levels well below that corresponding to claims of excess heat - again more information is necesary to judge

7.4.10 Prof. Huggins of Stanford University has reported 12% excess heat based on observing that the cathode got warmer when D2O was used than when H2O was used - however this is natural given the different properties (e.g. heat capacities) of the two systems - but await more information, including these effects being taken into account.

7.5 Summary of Positive and Negative Results

There are a number of experiments that have given positive results, but if one asks that the experiments have all the checks done (including H2O and dummy cathodes), be well analysed with conventional statistics and show a statistical significant effect consistently, then I do not know of one which satisfies these normal scientific requirements.

On the other hand there are groups which have done careful work, explained it, obtained consistent results, but these groups all obtain null results i.e. they observe no cold fusion effects. Examples are Harwell, Karlsruhe, Yale-BNL, ATT, Bugey-Frejus, Caltech and several others.

Many of the groups obtaining positive results emphasise that the effects they observe are sporadic and irregular. They cannot predict when they happen. Normally this is taken as a sign that the results are untrustworthy. But this is turned into an advantage saying it shows this is something new and needs further investigation. But before further investigation it is necessary to establish that any effect is taking place at all and this means doing an experiment that meets with the criteria of normal science. If one wishes to believe the effect is caused by fusion then a reasonable experiment would try to observe more than one fusion product simultaneously and do the elementary check that the rates deduced from each fusion product are in agreement.

If only there were one good experiment that was well done and well described. Just one.

8. OTHER ITEMS

8.1 Visit to Harwell

Visited Harwell and spent some time with David Williams. Discussed the Harwell work - it is very impressive and extensive. They have written a major paper for Nature, but when I checked with David today, they still had not heard whether it has been accepted. But the essential results are they they do not see any excess heat, neutrons, gammas, tritium or helium and have been able to give upper limits on processes which are very low.

8.2 Report from Berlin

Prof Marx of the Freie University of Berlin (who had worked with Prof. Kreysa of Frankfurt) told me that they had put tritium also in their cell and found that they quickly had DTO. They looked for neutrons and found "nothing, absolutely nothing"

8.3 Comments on DOE Panel report by Dr Pons and Senator Garn

The Deseret News printed comments on the interim report of the Department of Energy Panel by Dr. Pons;

"'It's a totally useless committee that is telling untruths. It serves no purpose.' He said he agreed with a statement made by Senator Jake Garn, R-Utah.

Garn critised what he sees as dirty politics in the scientific community for smearing cold fusion research and ruining its chances for large federal spending.

'I used to think politicians were dirty, slimy dishonest people. I've decided that the scientists are far worse than politicians', Garn said.

'I wholeheartedly agree with him' Pons said. 'In fact I am thinking about changing professions and becoming a politician'".

[and I used to think US Senators were distinguished responsible people]

Actually Dr. Pons had started attacking the Panel in the Salt Lake Tribune the day before, agreeing with Dr. Bockris that it was a "killer commission" and attacking Nature editor John Maddox especially because of his editorial calling on scientists 'to dismiss cold fusion as an illusion'. "'John Maddox's problem is he only reads his own newspaper", Dr. Maddox said, emphasising that Nature 'is a newspaper not a scientific journal.'"

[Pity, I've just ordered Nature and rather enjoy it].

8.4 Paper from Madrid

In June was invited to go to Madrid where the group of Carlos Sanchez had detected neutrons with a BF3 detector plus some gammas and variations in tritium concentration. They have now sent me a copy of their paper which will be published in Solid State Comm. The paper gives the data and at the foot of the table is written "After finishing this record (on 9 June) the current was switched on and the experiment is still running in the same conditions. From that day until now only background-like signals have been recorded from detectors and counters." [Carlos is a very kind man and I was most impressed by a physics course that he has set up for blind students, which particularly interested me. There are also practical demonstrations that he has built. In Note No. 15, I asked if any other university had a similar course for blind students. So far I have had no replies - does this mean that Carlos's course is the first?]

8.5 Changes at Los Alamos

In the subject of cold fusion, Los Alamos has tried to be very fair and even-handed. However at the Santa Fe conference that they mainly organised with varible success, people from Los Alamos presented results which both established cold fusion and showed that it did not occur. The null results have not, as far as I know, been questioned, but the reports of positive results have been controversial. At the meeting, after the evidence for neutron bursts had been presented, I asked if the essential control experiment of using normal H2O had been done and was told by Dr. Menlove that it had not been done but they would do it next. However they have now issued a preprint in which other experiments have been added but this promised check is not reported. Have asked their BYU collaborator several times about this but so far have not had a reply. Now I hear from various sources that they have trouble repeating these sporadic bursts - it would be good to have this cleared up. There is also considerable confusion over the press reports that Drs Storms and Talcott had found tritium but the Lab called the results preliminary. Again they may be having trouble repeating their results. The Wall Street Journal of 19 July carried an advertisement for a Director and Deputy Director of Public Affairs.

[It is often difficult to be fair and balanced. For example if you were making a film where the earth is shown to be round, would you agree to a demand from a member of theFlat Earth Society for equal space to show the earth was flat?]

8.6 European Physical Society

It is interesting to see how opinion among physicists changes with time about cold fusion. In May the American Physical Society organised two sessions on cold fusion but for their bi-annual meeting next month the European Physical Society has decided that cold fusion should not be discussed.

8.7 High Altitude Cold Fusion

In the August 21 edition of Community College Week, it is reported that at Colorado Mountain College they are trying cold fusion in their science lab which is at 10 000 feet. This is part of a large project by Rockwell International to test several variations of the Utah experiment. Associate professor Peter Jeschofnig and student volunteers have monitored the cold fusion experiment using equipment supplied by Rockwell. The company collected the data files as well as gases generated by the experiment to conduct further research. Dr. Jeschofnig said "the college altitude test did appear to generate fusion. It looks like a positive test" he added. Rockwell received funding for its test through the Department of Energy. At other sites the company is using several other variations in addition to altitude.

The aim of the study at high altitude was to look for muon-generated fusion. It is possible that it was not known that more decisive and better controlled experiments have been performed and reported on of tests on cold fusion using muon beams. Also theoretically one would expect the muons to be quickly trapped on the high-Z palladium cathode.

Douglas R. O. Morrison

PS There is no truth in the rumour that the five-foot cathode is really intended for Kali.
PPS Some scientists in Utah have begun to refer to the inconsistencies coming out of the Cold Fusion establishment as HEAVYWATERGATE.

NOTE ON LEP

During the five or so days of the pilot run of LEP, some collisions were obtained during less than 16 hours and the four experiments found a total of over 50 examples of Z0 events. Commissioning of LEP is continuing and a beam of over one milliAmp has been obtained. It is planned to start a physics run on 11 September.

3.2

Richard L. Garwin
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July 18, 1989

Dr. Etienne Roth
Professeur au Conservatoire National
des Arts et Metiers
Desicp Cen Saclay
91191 Gif-Sur-Yvette Cedex
FRANCE

Dear Professor Roth:

It was a great pleasure to have you visit in La Jolla Saturday, 07/15/89. I look forward to seeing you and your colleagues in Paris.

You might be interested in the enclosed FAX I have just sent Kevin Wolf, as we discussed.

There is one difference between the FAX and what I mentioned to you in La Jolla. I indicated that even if there were not the usual 1:1 branching ratio in fusion, there would be plenty of neutrons, in any case, because the 3 MeV proton would disintegrate deuterons, which have a threshold, as we know, of 2.2 MeV. On reflection in preparing to write this FAX, I recalled that it is, of course, the energy in the center of mass that counts, and for a mass-1 particle incident on a mass-2 particle, this is only 2/3, or 2.0 MeV.

I hope that you had a good return trip to Paris, and I will certainly let you know when I visit next.

Sincerely yours,

Richard L. Garwin
Forwarded in his absence

Encl:
07/17/89 LTR RLG to K.L. Wolf re tritium production in electrolytic cells.

RLG:jah:199%ER:071889..ER

Also Adjunct Professor of Physics at Columbia University
(Views not necessarily those of IBM or Columbia)

U.S. DEPARTMENT OF COMMERCE
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National Institute of Standards and Technology
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Gaithersburg, Maryland 20899

-R.L.GARWIN-
[illegible] JUL [illegible] NO. 16

July 24, 1989

Richard L. Garwin
IBM Fellow & Science Advisor
to the Director of Research
IBM Corporation
Yorktown Heights, NY 10598

Dear Professor Garwin:

Enclosed please find the preprint "Coulomb assisted cold fusion in solids." This paper describes a mechanism which indicates that actual cold fusion may be compatible with the usual quantum mechanics and does not require outlandish assumption. I hope you will find this paper interesting, and I would be very happy to hear of any comments you may have.

Sincerely yours,

Michael Danos
Center for Radiation Research
Nuclear Physics Group

Enclosure

072489..MD

Submitted to Nature
17 July 1989

COULOMB ASSISTED COLD FUSION IN SOLIDS

Michael Danos
Center for Radiation Research
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Gaithersburg, MD 20899

ABSTRACT

In a process where the fusion leads directly to the ground state of the final nucleus, which requires the presence of a third nucleus, the regular and irregular Coulomb solutions conspire to dramatically increase the Coulomb barrier penetration. The characteristics of this effect, and the limits of its validity, are described.

Experimental results recently have been published[1,2] which suggest that light-element fusion occurs in solids having the capability of carrying hydrogen. In particular the work of Jones et. al[1] must be mentioned in this context since it reports the observation of a signal, viz. neutron emission from Pd and Ti electrodes in an electrolytic cell, which unequivocally would demonstrate the occurrence of a nuclear reaction. These results have been reproduced by other workers (several papers, this volume). However, no generally acceptable interpretation of these results is available at this time. And, as is well known, these results appear to be incompatible with the extant theoretical attempts at explaining the observed reaction rates (the most recent calculations are given in the following preprints: J. Rafelski, M. Gajda, D. Harley, and S. E. Jones, University of Arizona Preprint AZPH-TH/89-19-2 and A. J. Leggett and G. Baym, University of Illinois, Urbana, Department of Physics preprint May 3, 1989), which exceed the theorical rates by a factor 10^{20}-10^{40}.

Recognizing all the tentativeness of the situation, it is nevertheless not premature to pose the question of the physical implications of the results of Ref. 1, and even perhaps of Ref. 2, since they very well may turn out to contain some truth. In that case, of course, full understanding of the physics will be required. The present paper is an attempt to take the first steps in that direction, which, in fact, consist only in identifying and describing a mechanism which has the potential of bridging the gap between the experimental and theoretical reaction rates. In this paper no other questions will be raised. In particular, the question which of the possible reactions are responsible for the observations will not be addressed.

A full description of the cold fusion process at this point in time is clearly out of the question since it takes place in a solid matrix, and, as is indicated by the experimental data, only under (not understood) exceptional conditions. Even stripping the process down to the simplest, perhaps over-simplified, ingredients, the cold fusion process involves 3 nuclei, viz. the two fusing nuclei and the (catalyzing) nucleus which is sharing the liberated energy and momentum. Therefore an exact treatment of this stripped down description would demand the solution of a full-fledged 3-body problem, which would have to be performed by numerical techniques. (The different problems associated with such a treatment have been discused at great length in the context of the analogous case of d-t-μ fusion in Ref. 3.) This procedure, besides being very cumbersome, leads to non-transparent results where the underlying physics is hard to extract. On the other hand, the underlying physics is clearly established when using a perturbation treatment. As we will show the qualitative aspects of the reaction are fully contained in the results of such a treatment. We therefore will discuss the problem by means of a perturbation treatment. The validity of such a treatment deserves a careful discussion. We shall do this in the second part of the paper. The first part is devoted to describing the proposed mechanism and deriving its consequence.

We now give a description of our procedure, which, as mentioned, serves to render the 3-body process tractable. To that end recall that the essential difference between a 2-body and a 3-body system is that after separation of the CM motion the relative energy in the former is a fixed quantity. In contrast, in the 3-body system the internal energy is shared between the three particles; the energy partition there is a dynamic variable. This can be seen immediately by introducing a Jacobi coordinate system for the relative motion. Even though the kinetic energy separates in these coordinates the potential energy — which depends on the inter-particle distances — does not. To reduce our problem to manageable complexity we shall use the following perturbation scheme. (i) We treat the fusing nuclei as a 2-body system taking into account the mutual Coulomb repulsion. (ii) We account for the energy-momentum sharing with the third particle, viz. the catalyzing lattice nucleus — which is needed for overall energy-momentum conservation — by perturbation in first order. These two assumptions lead to a description which is fully analogous to that of the internal conversion process in which the role of the catalyzing nucleus is played by the converted electron (see, for example, Chapter XII of Ref. 4). This way within our assumptions the fusion process is described by the two Feynman graphs, Fig. 1a, 1b. In the reaction according to Fig. 1a the fusion takes place first while the energy-momentum sharing takes place after the fusion. In Fig. 1b the energy-momentum exchange takes place before the fusion, and the fusion reaches directly the ground state of the final nucleus. We will see that these two processes result in vastly different reaction amplitudes.

Derivation of the Results

The essential difference between the fusion process in free space and in a lattice is the availability of a catalyst, i.e., of a near-by lattice nucleus which serves as the third body needed to fulfill the requirements of energy-momentum conservation. This mechanism is the same for any choice of fusing and catalyzing nuclei. In order to fix the language we consider the case of radiationless p + d fusion in a Pd lattice. Then we have

$$p + d + Pd \rightarrow {}^{3}He + Pd + Q \qquad (1)$$

where the fusion releases the energy $Q \simeq 5.4$ MeV. Also, we take particle 1 (Fig. 1a, 1b) to be Pd, particle 2 to be d and particle 3 to be p. Inasmuch as the system is extremely non-relativistic the description can be reduced to solving appropriate Schrödinger equations in position space, after the energy conservation implied by the Feynman graphs has been taken into account. We now give the details.

We now write down the non-relativistic first order transition matrix element. For both Fig. 1a and 1b it has the form

$$M \simeq \int \psi_f^*(\vec{x}_1)\, \psi_i(\vec{x}_1) \left[\frac{1}{|\vec{x}_1-\vec{x}_2|} + \frac{1}{|\vec{x}_1-\vec{x}_3|}\right] \psi_f^*(\vec{x}_2,\vec{x}_3)\, \psi_i(\vec{x}_2,\vec{x}_3)\, d^3x_1 d^3x_2 d^3x_3 \ . \quad (2)$$

The difference between the reaction 1a and the reaction 1b lies in the form of the wave functions for particles 2 and 3, i.e., $\psi_i(\vec{x}_2\vec{x}_3)$ for the initial state, while $\psi_f(\vec{x}_2\vec{x}_3)$ for the final state and $\psi_f(x_1)$ and $\psi_i(x_1)$ for particle 1 are the same for both cases. Thus, for reaction 1a, $\psi_i(\vec{x}_2,\vec{x}_3)$ is that of a highly excited (5.4 MeV) ^{3}He nucleus, while for reaction 1b, $\psi_i(\vec{x}_2,\vec{x}_3)$ is the solid state wave function of the p and d in the hydride while $\psi_f(\vec{x}_2,\vec{x}_3)$ is that of the ^{3}He ground state in both cases. As will become clear below, it is the fact that the fusion leads directly to the ground state of ^{3}He which is essential in achieving penetration of the Coulomb barrier.

We begin with the angular parts. In view of the fact that the required momentum transfer $|\vec{q}| \sim \text{fm}^{-1}$ while the interparticle distances are ~ Å we see that ℓ-values up to $\sim 10^4$ are involved, while the ^{3}He ground state has $\ell = 0$. Alternatively one can say that here a description by ray (rather than wave) optics is called for. This implies that in order for the reaction to occur the Pd, p, d nuclei must be lined up within an accuracy ~ fm. Either way, the angular overlap will yield a factor $(\text{fm}/\text{Å})^2 \sim 10^{-8}$ in the case of uncorrelated angles. In case of correlations, resulting from the wave functions $\psi_0(t)$ of the graphs Fig. 1a, 1b, this factor may be modified from the above value by many orders of magnitude, as it may involve the small tails of $\psi_0(t)$.

We now proceed to compute the wave function for the relative motion of particles 2 and 3. To that end we separate the CM and relative coordinates of the $(\vec{x}_2,\vec{x}_3)$ system. Thus

$$(m_2 + m_3)\,\vec{X}_{23} = m_2\vec{x}_2 + m_3\vec{x}_3$$

$$\vec{x}_{23} = \vec{x}_2 - \vec{x}_3 \quad . \qquad (3)$$

Introducing now the notation r for the distance between particles 2 and 3 we see that in order to evaluate the matrix element (2) we need to know $\psi(r)\big|_{r=|\vec{x}_{23}|}$, where $\psi(r)$ obeys the radial part of the Schrødinger equation (here E is not an eigenvalue in view of the energy sharing with particle 1) $(\hbar = c = 1)$

$$\left(-\frac{1}{2\mu}\frac{d^2}{dr^2} + \frac{\ell(\ell+1)}{r^2} + V(r) - E\right)\psi(r) = 0 \qquad (4)$$

where $\mu^{-1} = m_2^{-1} + m_3^{-1}$ is the reduced mass. Furthermore, $V(r)$ is the Coulomb potential for $r > \rho$ and the effective nuclear potential $0 < r < \rho$, where ρ is the range of the nuclear forces. Of course, in the region $r < \rho$ the coordinate r loses physical meaning since there the composite particles, i.e., here d, dissolve into the constituents. Nonetheless, one can continue r even into that region by introducing an effective one-body potential which can be chosen to yield agreement between theory and experiment over a given energy range — as is commonly done in the optical model of nuclear physics. We denote the solution of (4) for $r < \rho$ by $\psi_{nucl}(r)$.

We continue by considering the region $r > \rho$, i.e., the Coulomb barrier. In that region eq. (4) commonly is solved by means of the WKB method. The two (not normalized) solutions then are

$$\psi_{reg}(r) = e^{X(r)} \tag{5}$$

$$\psi_{irreg}(r) = e^{-X(r)} \tag{6}$$

with

$$X(r) = \int_{\rho}^{r} dr' \; \kappa(r') \tag{7}$$

and

$$\kappa(r') = \{2\mu \; [\; \frac{\ell(\ell+1)}{r'^2} + \frac{e^2}{r'} - E] \; \}^{1/2} \tag{8}$$

As evident from (5) through (8), $\psi(r)$ can be a very sensitive function of E. The solution in the Coulomb region then is

$$\psi_{Coul}(r) = A\psi_{reg}(r) + B\psi_{irreg}(r) \quad . \tag{9}$$

In order to determine the amplitudes A and B one must match wave functions and derivatives of the Coulomb region and the nuclear region at the nuclear radius $r = \rho$. Within the accuracy of the WKB method we have from (5), (6), and (7)

$$\psi'_{reg}(r) = \kappa(r)\, e^{X(r)} \tag{10}$$

$$\psi'_{irreg}(r) = -\kappa(r)\, e^{-X(r)} \quad . \tag{11}$$

We now are prepared to write down the Coulomb wave function and its devirative at $r = |\vec{x}_{23}|$ needed in the matrix element (2). For brevity we introduce the notation $R \equiv |\vec{x}_{23}|$ and $X \equiv X(R)$. In view of (9) we have

$$\psi'_{Coul}(R) = \kappa(R)\, [A\, e^{X} - B\, e^{-X}] \tag{12}$$

$$\psi_{Coul}(R) = A\, e^{X} + B\, e^{-X} \quad . \tag{13}$$

Similarly for $r = \rho$ we have in view of (7)

$$\psi'_{Coul}(\rho) = \kappa(\rho)\, [A - B] \tag{14}$$

$$\psi_{Coul}(\rho) = A + B \quad . \tag{15}$$

Combining these equations we find the propagation matrix which propagates the wave function from $r = \rho$ to $r = R$:

$$\begin{pmatrix} \frac{1}{\kappa(R)}\, \psi'_{Coul}(R) \\ \psi_{Coul}(R) \end{pmatrix} = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} \begin{pmatrix} \frac{1}{\kappa(\rho)}\, \psi'_{Coul}(\rho) \\ \psi_{Coul}(\rho) \end{pmatrix} \quad . \tag{16}$$

Here

$$T_{11} = T_{22} = \cosh X \quad , \tag{17a}$$

$$T_{12} = T_{21} = \sinh X \tag{17b}$$

which thus are functions of R. We only note that the matrix elements of (16) always can be parametrized in the form (17) which ensures unitarity, i.e., det(T) = 1; it is only the explicit form (7) which is approximate.

To complete this development we must implement the matching conditions

$$\psi'_{Coul}(\rho) = \psi'_{nucl}(\rho) \quad , \tag{18a}$$

$$\psi_{Coul}(\rho) = \psi_{nucl}(\rho) \quad . \tag{18b}$$

We thus must investigate the characteristics of the nuclear wave function $\psi_{nucl}(\rho)$.

At this point the reactions Fig. 1a and 1b show a decisive difference. We consider first the reaction Fig. 1b. There the energy of the final state is very close to the ground state energy $E_0 = -Q$. From general considerations (see, e.g., Chapter X of Ref. 4) one knows that in the vicinity of E_0 the logarithmic derivative obeys the equation (neglecting higher powers of $(E-E_0)$)

$$\left.\frac{\psi'(r)}{\psi(r)}\right|_{r=\rho} = -\kappa_0 - K(E - E_0) \tag{19}$$

where K depends on ρ and on the nuclear dynamics and κ_0 is given by (8) for $r' = \rho$ and $E = E_0$.

In order to have definite analytic expressions we shall replace the actual nuclear system by a model where the nuclear interactions are simulated by an attractive square well of radius ρ. Chosing the well depth such that at energy E_0 the logarithmic derivative of the wave function equals $-\kappa_0$, the model will yield

$$\psi_{nucl}(\rho) = aN \sin k\rho \qquad (20)$$

$$\psi'_{nucl}(\rho) = aN\, k\cos k\rho \quad . \qquad (21)$$

Here N normalizes the wave function within the well and a is the amplitude for the wave function within the nuclear volume; it will be determined below. From (20), (21) we have

$$\frac{\psi'_{nucl}(\rho)}{\psi_{nucl}(\rho)} = k \cot kr \Big|_{r=\rho} = -\kappa_0 - D(E-E_0) \quad . \qquad (22)$$

It is, of course, easy to chose ρ and the well depth, i.e., k, such that (22) is fulfilled. However, the slope parameter K, eq (19), is not accessible from experiment. Hence ρ and k cannot be separately determined. Still, chosing for ρ a magnitude of nuclear size, one can expect that D and K will be of similar order of magnitude even though $D \neq K$ (see, e.g., Chapter VIII of Ref. 4).

As the final step we insert (20), (21) in (16) to obtain [here $\kappa_0 \equiv \kappa_0(\rho)$]

$$\frac{1}{\kappa_0(R)}\, \psi'(R) = a(k/\kappa_0)\, N \cos k\rho \cosh X + aN \sin k\rho \sinh X$$

$$= \frac{aN}{2\kappa_0}\, e^{X} \sin k\rho \left[(\kappa_0 + k \cot k\rho) - e^{-2X}(\kappa_0 - k \cot k\rho)\right] \qquad (23)$$

$$\psi(R) = a(k/\kappa_0)\ N \cos k\rho \sinh X + aN \sin k\rho \cosh X$$

$$= \frac{aN}{2\kappa_0} e^X \sin k\rho\ [(\kappa_0 + k \cot k\rho) + e^{-2X}(\kappa_0 - k \cot k\rho)] \tag{24}$$

Squaring (23) and (24) and summing we can solve for a^2:

$$a^2 = \frac{2[R^2]}{D\ M^2} \quad \frac{\Gamma/2}{(E-E_0)^2 + \Gamma^2/4} \tag{25}$$

with $E_0 = -Q$ and the following definitions:

$$\kappa_0 + k \cos k\rho = -D(E-E_0) \quad , \tag{26}$$

$$\Gamma/2 = (2\kappa_0 e^{-2X})/D \quad , \tag{27}$$

$$M^2 = (N \ \sin k\rho)^2 \quad , \tag{28}$$

and where

$$[R^2] = (\kappa_0(R)^{-1}\ \psi'_{Coul}(R))^2 + (\psi_{Coul}(R))^2 \quad , \tag{29}$$

is the "strength" of the wave function, in essence outside of the Coulomb barrier. In (27) we have replaced $\kappa_0 - k \cot k\rho$ by $2\kappa_0$. Finally, we compute

$$W = \int dE\ a^2 = \frac{2\pi\ [R^2]}{D\ M^2} \quad . \tag{30}$$

We see that even though the width of the resonance is exceedingly small, i.e., $\Gamma \sim 10^{-40}\ \kappa$, in W, eq. (30) the Gamov factor indeed disappears, i.e., the intgrated strength is of order unity. Also one sees that this effect can exist only for the ground state; for any other resonance at least the electromagnetic decay channel is open and will dominate the reaction since its width will always be many orders of magnitude larger than Γ, eq (27). This case has been carefully discussed by Kauffmann and Rafelski.[5]

The next question concerns the wave function $\psi_i(r_{23})$, i.e., the wave function of the initial state, which we need at $r_{23} \gtrsim R$, i.e., at atomic distances. Because of the electrons of the lattice there the Coulomb barrier has no influence, and in the case of a fully loaded hydride the wave function has a value of the order of magnitude $V^{-1/2}$, where V is the volume of the unit cell. Compared with the final-state wave function its influence on the magnitude of the matrix element is minor, i.e., yielding a factor of at most some small powers of 10.

We now turn to the reaction Fig. 1a. It is immediately clear that here the Coulomb barrier acts in full force. Namely, being far removed from any resonance the logarithmic derivative of the channel wave function at $r_{23} = \rho$ has a non-exceptional value so that the matching will yield some non-exceptional ratio of the amplitudes of the regular and the irregular solutions. Consequently only the regular solution survives for $r_{23} \sim R$. Thus the contribution of this reaction to the fusion process has a value consistent with the extant estimates (see the previously referred to preprints by Rafelski, Gajda, Harley and Jones; and by Leggett and Baym) and is negligibly small relative to the contribution of the reaction Fig. 1b.

Concerning the higher order terms in the perturbation expansion consider the case where 2 hard Coulomb photons are exchanged. The cancellation between the regular and irregular solutions in eq. (9) still can take place for the Coulomb barrier between the fusion radius ρ and the point of emission of the second photon, R_2, but this cancellation will not take place for the barrier between R_2 and R_1, the point of emission of the first photon, thus resulting in an exponentially small contribution to the reaction rate. Hence, the higher order terms of the perturbation expansion can be safely neglected.

Validity of the Derivation

Our results, eqs. (25) and (30), were obtained by evaluating the transition operator, here the Coulomb force (cf. the matrix element eq (2)), in first order in a time-independent treatment. In view of the fact that the width turns out to be astronomically small — even though the integrated cross section retains a physically accessible value — the question arises about the applicability of the usual interpretation of the perturbation theory results. In order to investigate this question we re-visit the derivations of these results and we will do this in the framework of the time-dependent perturbation theory.

Following, for example, the treatment of Schiff,[6] Chapter VIII, we see that the structure of the system does not enter the description until one obtains (in Schiff's notation)

$$a_{km}(t) = -H'_{km}\,\frac{e^{-i\omega_{km}t} - 1}{\omega_{km}} \quad , \tag{31}$$

and writes the final result for the transition probability as

$$W_m = \frac{\rho(k_0)}{t}\int dE_k\;|a_{km}(t)|^2 \tag{32}$$

In (31) the indices k and m denote the final and initial states, respectively, $a_{km}(t)$ is the time-dependent counterpart of our a, eqs. (20), (21), W_m of (32) is equivalent to our W of (30), while H'_{km} is our matrix element M, eq. (2). The basic question now is whether the form (32) for computing the transition probability is justified, i.e., whether one is permitted to square the amplitude before summing, since this implies that one ignores possible interference effects between the different parts contributing to the sum (integral) in (32). In other words one must ask whether instead of (32) one should write

$$W' \simeq | \int dE_k \, a_k(t) |^2 \quad , \tag{33}$$

i.e., whether one should be summing before squaring. To decide between these possibilities one must go back to the preceding step in the development. As we now demonstrate, the answer to this question depends on the "preparation" of the system, and on the time available for the observation. Let us begin with the second of these points.

Consider the transition probability arising from a superposition of states

$$V = \frac{1}{\tau} \left| \int_T^{T+\tau} dt \int dE \, a(E) \, \varphi(E) \, e^{-iEt} \right|^2 \tag{34}$$

with a(E) of the form obtained from (23) or (24). For T, $\tau \ll E_0^{-1}$ we find that, as long as $\varphi(E)$ does not change substantially over the width Γ, there holds

$$V \to 0 \tag{35}$$

On the other hand, for T, $\tau \gg E_0^{-1}, \Gamma^{-1}$,

$$V \to \int dE \, |a(E)|^2 \, |\varphi(E)|^2 \tag{36}$$

i.e., in that limit we recover the prescription (32). This demonstrates that indeed the prescription (32) is not of universal validity. In fact, these results, in particular eq. (35), are leading to the effects known in the literature as the "non-exponential part" of the decay of an unstable system:[7,8] at the very beginning, depending on the preparation of the state, as a consequence of the interference of the different components of the wave function the decay curve begins with a horizontal tangent; for a little while the system looks stable. In the present case that translates into a vanishing reaction rate.

Evidently the condition $\tau \gg \Gamma^{-1}$ cannot be fulfilled in our case. We thus must see which other aspects are involved in leading to the result (35). To that end we return to (31). This equation arose after specifying that the initial state is given by

$$\Psi_i = \int b(E)\ \varphi(E)\ dE \tag{37}$$

with

$$b(E) = \delta(E - E_m)\quad . \tag{38}$$

However, dropping (38), i.e., retaining (37) in its full generality does not change the result (35). In words, as long as the state of the fusing system is given by a wave function the reaction rate vanishes. This is different if one deals with a system which requires for its description a density matrix (M. Danos, Theory of Cold Fusion, previously submitted as Abstract to the post-deadline Session on Cold Fusion, APS Baltimore Meeting, May 1, 1989), i.e., a system where the density matrix cannot be factorized.[9] Indeed, writing for the density matrix

$$\rho_{E,E'} = \delta(E-E')\ |a(E)|^2 \tag{39}$$

we find, inserting (39) in (34)

$$V = \frac{1}{\tau} \int_{T}^{T+\tau} dt \int dE\, dE'\, \rho_{E,E'}\, \varphi^{*}(E)\, \varphi(E')\, \ell^{-i(E'-E)t}$$

$$= \int dE\, |a(E)|^{2}\, |\varphi(E)|^{2} \quad . \tag{40}$$

To derive this result more formally recall that the transition rate is given by

$$W \simeq \mathrm{Tr}\,(\rho_i \Omega) = \mathrm{Tr}(\rho_i H_1 \rho_f H_1) \tag{41}$$

taking into account the fact that the perturbing Hamiltonian H_1 is Hermitean. The result (40) follows for non-factorizable density matrices of the form (39). And, as is well known, fully thermalized systems are described by such density matrices.

In summary, we have indicated that a mechanism exists which has the potential of leading to an effective lowering of the Coulomb barrier thus allowing for a substantially increased cold fusion rate. This way the factors which limit the rate in this mechanism turn out to lie not in the Coulomb barrier but in other aspects of the quantum character of the system, in particular in the details of the density matrix describing the system, and in geometric correlations of the participating nuclei. An exact evaluation of these effects would require the knowledge of very subtle characteristics of solids; conversely, any quantitative observations of actual fusion reactions would yield information on these characteristics.

ACKNOWLEDGMENTS

I would like to thank L. Wilets and R. Madey for several useful discussions.

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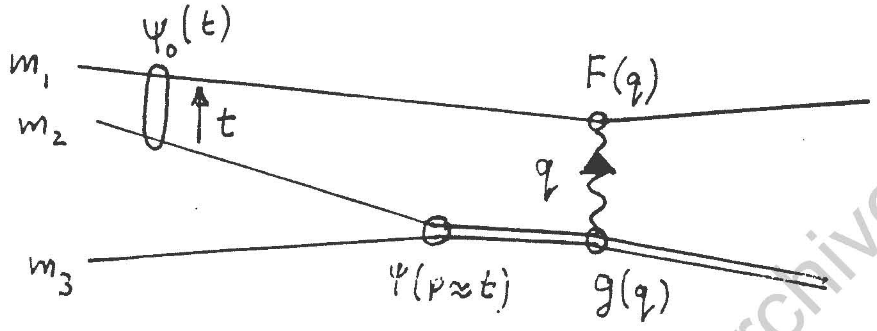
FIGURE CAPTIONS

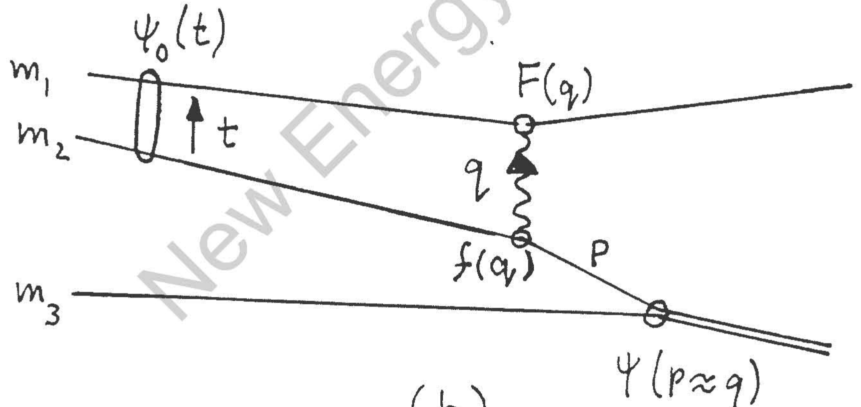
Fig. 1. Feynman graphs for the radiationless fusion. m_1: catalyzing (lattice) nucleus; m_2, m_3: fusing nuclei; $\psi_0(t)$: momentum space "trapping" wave function; F(q), f(q), g(q): electron scattering form factors; $\psi(p)$: momentum space fusion channel wave function.

a: recoil exchange after fusion;

b: recoil exchange before fusion.


$\psi_0(t)$
m_1
m_2
m_3
t
$F(q)$
q
$\psi(p \approx t)$
$g(q)$

(a)


$\psi_0(t)$
m_1
m_2
m_3
t
$F(q)$
q
$f(q)$
P
$\psi(p \approx q)$

(b)

(3.4)

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August 11, 1989

Dr. Michael Danos
Center for Radiation Research
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and Technology
Bldg 245, Room B109
Gaithersburg, MD 20899

Dear Dr. Danos:

Thank you for your note of 07/24/89 and the enclosed preprint of 07/18/89, "Coulomb Assisted Cold Fusion in Solids." While I understand that a calculation for comparison with experiment might need to take into account "very subtle characteristics of solids," I would still like to see a model calculation which would at least show me one example of a calculated rate. I would like to see numbers.

For instance, the model could be two deuterium atoms in a small box with a single (modelled) high-Z atom.

Thank you.

Sincerely yours,

Richard L. Garwin

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-R. L. GARWIN-

UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
[formerly National Bureau of Standards]
Gaithersburg, Maryland 20899

August 21, 1989

Richard L. Garwin
IBM Research Division
Thomas J. Watson Research Center
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Dear Dr. Garwin:

As you note in your letter of August 11, 1989, my preprint on "Cold Fusion" of 07/18/89 concerns itself only with pointing towards the existence of previously ignored effects which, when taken into account, have the potential of changing the expected magnitude of the cold fusion rate by many orders of magnitude. However, no numbers were reported in that paper. Let me then begin by supplying that information, while below I shall expand a little on the preprint, pointing toward the next steps. The point of departure from the "standard" treatment is eq. (9) of the 07/18/89 preprint, in that it allows $B \neq 0$, i.e. the presence of the irregular Coulomb function in the solution. Thus, the "standard" solution is reproduced if ~~our~~ one drops in (23) and (24) the first term in the brackets. Going through the algebra one finds that this results in achieving for a^2, eq. (25), the off-the-resonance value, which contains the factor e^{-2X}. This factor is the "standard" Coulomb penetration factor for which depending on the model, values 10^{-20} to 10^{-50} have been reported. Thus the numerical result of the "naive" rate, i.e. the rate computed with eq. (41) assuming a fully thermalized system, turn out to be in the range 10^{-10} to 10^{-20} sec^{-1}/(fusing pair). This value I reported at the NATO Summer School, May 1989, "The Nuclear Equation of State." I enclose the write-up of that lecture.

However, as explained to some length in the 07/18/89 preprint, a non-thermalized state would yield zero fusion rate. Hence, the above numbers represent limiting fusion rates. In fact, this dependence on the character of the density matrix to be thermalized may be - in terms of a wild speculation - suspected to be the reason for the observed irreproducibility of the fusion rate (cf. the Texas A&M tritium production), and the erratic behavior even after tritium production has commenced. Here the speculation:

The deuterium in the Pd lattice may be in a coherent BCS-type state. Still, since the d is only a pseudo-Boson the coherent state actually must be split, i.e. must be a very dense spectrum of $\sim 10^{23}$ states; level spacing $\sim 10^{-26}$ eV (assuming, a total width ~ 1 meV). Since the width Γ, eq. (27) is $\sim 10^{-40}$ it is very much smaller than the level spacing; there may not be any overlap between the line, eq. (25), and the available states. While the electrolysis is taking place, this coherent deuterium state is brought into contact with an external heat bath, by means of the incoherently entering deuterons; rate $\sim 10^{19}$/sec. This thus may be acting as a coherence destroying input. After 2 weeks some 10^{25} such random de-coherenting events will have happened. This may suffice to allow for

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"naive" fusion to take place. In this (speculative) mechanism one may "understand" the role of the electrolysis. Also, switching off the current would interrupt the thermalization; as the resonating states, which can undergo fusion, react the potential fusion population disappears and the reaction stops. Of course, this speculation is too wild for publication.

I only want to mention that other processes, in addition to the lowest order process of the 07/18/89 preprint, are possible. For example, the next higher order photo-disintegration process of Fig. 1 has the

1

2

3

potential of yielding a very large (p + t)/(^{3}H + n) branching ratio since in the former the neutron is absorbed by the deuteron 3, while in the latter it is the proton (which experiences Coulomb repulsion) which must be absorbed by 3.

In closing I want to mention that to my best knowledge only one other physicist, namely V. Belyaev, Dubna, has reported similar thoughts.

Sincerely yours,

Michael Danos
Center for Radiation Research
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COULOMB ASSISTED COLD FUSION

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INTRODUCTION

By now several experiments have been reported which suggest that light-element fusion occurs in solids having the capability of carrying hydrogen. The present lecture contains a formulation for the computation of the fusion rates, and an estimate of the order of magnitude of the rates which could be expected in semi-heavy water (HDO) and in hydrides.

Consider that a hydrogen, denoted by m_2 (say, a proton), is contained in a trap, next to a lattice nucleus, M, denoted by m_1. If a second hydrogen, m_3 (say, a deuteron), drifts past this site, as it reaches a position such that m_1, m_2, and m_3 are on a line with the Coulomb repulsion can impart a momentum to m_2 "propelling" it towards m_3 and at the same time transferring the recoil $\vec{q}$ and the energy E to m_1, keeping it on the mass shell. Hence m_2 now is off the mass shell. As m_2 reaches m_3, fusion takes place yielding the nucleus m_4 (here ^{3}He), and all particles are restored to be on the mass shell. The momentum space Feynman graph is shown in Fig. 1. Writing ($\hbar = c = 1$)

$$N(t) \sim \psi_0(t) \frac{1}{t_1{}^2 - m_1{}^2} \frac{1}{t_2{}^2 - m_2{}^2} \tag{1}$$

$$M \sim e^2 F(q)\ f(q)\ \psi(p) \frac{1}{q^2} \frac{1}{p^2 - m_2{}^2} \tag{2}$$

the matrix element of the graph is

$$R \simeq M \int dt\ N(t) \quad . \tag{3}$$

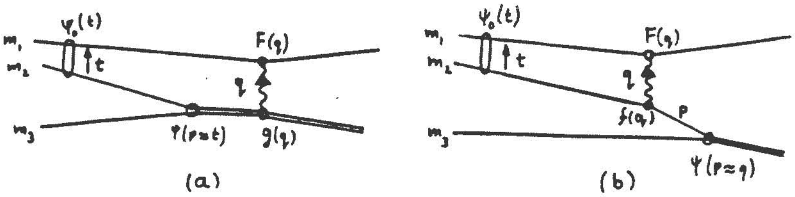

Fig. 1. Feynman graphs for Coulomb assisted fusion. m_1: lattice nucleus; m_2,m_3: fusing nuclei.

In (1) $\psi_0(t)$ is the trapping wave functions; very little is known about it except that the momenta $|t|$ are "small," appropriate to lattice physics, i.e., of the order d^{-1} where d is the lattice spacing. F(q) is the Coulomb vertex function of m_1, i.e., of the nucleus M, f(q) that of m_2 (the proton), and $\psi(p)$ is the nuclear fusion vertex function. Of these quantities F(q) is known from electron scattering; f(q) and $\psi(q)$, being half off-the-mass-shell, must be estimated from on-the-mass-shell experiments.

Even though here a time-independent treatment most probably is not practicable, it nevertheless is useful to take a look at the qualitative features of such a description as an aid in achieving an understanding of the process. Thus, being a stationary state description, the system would have standing waves in all channels. In other words, the time-independent treatment is a superposition of the reaction and its time-reverse. In order to give an illustration of the process, and to approach the description of the graphs of Fig. 1, we replace the full-fledged three-body Coulomb problem by a two-stage description, in the first stage dropping the Coulomb interaction between m_1 and the other particles, and regarding its effect in the second stage. Before fusion we have a three-body system, after the fusion a two-body system. This final state system is kinematically fully determined. Thus, taking A_1 to be ~ 100, we have the following kinematic conditions for the recoil to the lattice nucleus: for the p+d → ^{3}He reaction: $p_1' \approx 1$ fm^{-1}, $E_1' \approx 0.16$ MeV; for d+d → ^{4}He: $p_1' \approx 2$ fm^{-1}, $E_1' \approx 0.95$ MeV. Thus $t/p_1' \sim 10^{-5}$ and can be neglected. The energetics of the reaction is schematically illustrated in Fig. 2, where the (9-dimensional) configuration space is symbolically split into region I containing the 3-body system and region II containing the 2-body system. (Region I excludes the space $r_{dp} \lesssim a \simeq 5$ fm where nuclear forces become important). Three of the infinite number of configurations are illustrated. Figure 2a shows the distribution of energies corresponding to the initial state of Fig. 1. Figure 2b shows the energy distribution of the configuration corresponding to the intermediate state of Fig. 1b, i.e., the state of the system after exchange of the "Coulomb photon" q, but before fusion. Thus particle 1, the Pd nucleus, has its final energy and momentum while 2 carries the momentum of the final state of the fused (^{3}He) system. Particle 3 is still in its initial state. Figure 2c shows another of the possible configurations, where particles 1 and 3 have undergone a further energy-momentum exchange. This state thus requires the exchange of 2 "Coulomb photons" for it to be reached from the "initial" configuration, Fig. 1a.

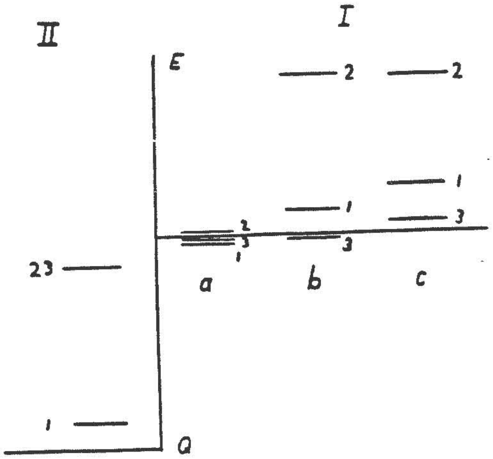

Fig. 2. Energies for different configurations: a. initial state; b. final state; c. some other configuration.

Region I: before fusion;
Region II: after fusion.

We now look at the qualitative behavior of the relative wave function of the m_2-m_3 subsystem. Consider first the configuration Fig. 2a. There the relative wave function is essentially exponentially damped owing to the Coulomb barrier (Fig. 4a). This wave function usually is computed by the WKB method. However, in contrast to the WKB wave function, at $r_{23} \sim a$ the solution requires the presence of the irregular Coulomb solution in order to allow the fulfilling of the matching conditions at the nuclear surface $r_{23} = a$. This admixture can for certain reconance conditions change the barrier penetrability by many orders of magnitude from the WKB value.

On the other hand, the wave function which corresponds to the configuration of Fig. 2b, being above the Coulomb barrier, remains oscillatory down to $r_{23} \approx a$. A very small admixture resulting from the action of V_{12}, V_{13}, will thus "circumvent" the influence of the Coulomb barrier. This is precisely the content of the graph Fig. 1b. In the time-independent Schrödinger picture the admixture of this configuration thus will be proportional to

$$A \sim \frac{\langle a|(V_{12} + V_{13})|b\rangle\langle b|(V_{12} + V_{13})|a\rangle}{\varepsilon_b - E}$$

which may be a small, but not "exponentially" small, number.

In order to estimate the fusion rate we must address the characteristics of the reaction. We observe that the wavelengths of the recoiling particles m_1 and m_2 are $\sim q^{-1} \sim 1$ fm, while the size, d, of the system is $\sim$ Å. Hence the motion of the particles is properly described by geometric (ray) optics rather than by wave optics. (Formally, this is related to the angular parts of the Fourier transformation.) This is the basis of the observation that m_1, m_2, and m_3 must be aligned. Only then can the Coulomb force, which has the direction given by $\vec{r}_2 - \vec{r}_1$, impart a momentum $\vec{q}$ (which thus also has the direction $\vec{r}_2 - \vec{r}_1$) which can carry m_2 towards m_3 resulting in fusion; m_3 must lie in the "shadow" of m_2. For uncorrelated positions this leads to a reduction factor

$$\eta_0 \sim (qd)^{-2} \approx 10^{-8}$$

Owing to the presence of correlations the actual reduction factor for fusion in such crystals thus can be very much smaller than η_0. For fusion to occur, therefore a special class of crystal imperfections is needed which would provide traps for hydrogen such that fusion alignment might occur. Simply using geometrical reasoning one finds that η in some cases could be as large as 10^{-4}. On the other hand, for example in HDO the alignment will be suppressed even further; here η may be as small as 10^{-14}.

Turning now to (3) we note that if the propagators in (1) were absent, the integral in (3) would yield $\psi(r_{12} = 0)$, i.e., it would essentially vanish. This, of course, is not the case. However one sees that the actual result depends rather sensitively on the (unknown) details of $\psi_0(t)$ in a rather involved manner since the propogators in position space are integral operators.

To estimate the reaction rates note that the central mechanism of Fig. 1 is the (off-the-mass-shell) Coulomb scattering of m_2 on the much heavier m_1. The other parts of the graph yield factors which decrease the reaction rate by differing amounts. Dropping numerical factors like P we estimate for the case of pd fusion in a palladium lattice: $(F(q))^2 \sim 10^{-2}$, $(f(q))^2 \sim 1$, $[\psi(p)/(p^2-m^2)] \approx 10^{-2}$, $[\int dt\ N()t)]^2 \sim 10^{-5} \times 10^{\pm 3}$, and $\rho v \sim 10^{-18}\ \mathrm{fm}^{-3}$. With the above estimate for the angular factor 10^{-4} we obtain

$$\mathrm{Rate(pd,\ lattice)} \approx 10^{-12} \times 10^{\pm 3}\ (\mathrm{trap\ sec})^{-1} \quad .$$

For dd fusion we estimate

$$(F(q))^2 \sim 10^{-4},\ (f(q))^2 \sim 10^{-3},\ \text{and}\ [\psi(p)/(p^2-m^2)]^2 \sim 10^{-4}.$$

Thus

$$\mathrm{Rate(dd,\ lattice)} \sim 10^{-17} \times 10^{\pm 3}\ (\mathrm{trap\ sec})^{-1} \quad .$$

To conclude, we give an estimate for heavy water. The main difference resides in the above mentioned angular suppression factor. Hence the HDO fusion rate is estimated to be around $10^{-24} \times 10^{\pm 3}$ (molecule sec)$^{-1}$, while in D_2O the rate may be a factor 10^5 smaller.

Energy Research Advisory Board
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August 28, 1989

TO: Members of the Cold Fusion Panel

Dave Goodwin asked that the attached paper be circulated for your information.

Bill

William L. Woodard
Panel Secretary

RLG Cold Fusion
Shelf

Aug.23,1989

FAX - FTS - 233-5079

Dr.David Goodwin
Special Assistant to the
Associate Director for
High Energy & Nuclear Physics
Office of Basic Energy Science,
Department of Energy
Washington,DC 20545

Dear Dr.Goodwin

I am enclosing the paper on the cold fusion which you might be interested in. This paper was presented to the Karlsruhe conference of ICENES and Dr.Iyengar sent me today.

Sincerely Yours

Hiroshi Takahashi

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COLD FUSION RESULTS IN BARC EXPERIMENTS

09/06/89

(91-22) 551-4910

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Fifth International Conference on Emerging
Nuclear Energy Systems (ICENES V)
Karlsruhe, Federal Republic of Germany
July 3-6, 1989

070389.PKI

H. Takahashi
received Aug. 23rd.

COLD FUSION RESULTS IN BARC EXPERIMENTS

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ABSTRACT

Experiments were initiated at Trombay during the first week of April 1989 to verify the widely reported claims of the occurrence of cold fusion. A large burst of ≈ 2×10^7 neutrons was first detected on April 21st with a Pd–Ni electrolytic cell. The neutron counting rate, averaged over a 5 minute interval, was a couple of orders of magnitude larger than that of background count rates. In this experiment the tritium level in the D_2O electrolyte jumped from the initial stock solution value of 2.6 Bq/ml to ≈ 5.6×10^4 Bq/ml, an increase by over four orders of magnitude. The total quantity of tritium generated corresponds to ≈ 10^{16} atoms suggesting a neutron to tritium channel branching ratio of less than 10^{-8} in cold fusion. Significant quantities of neutrons and tritium were also observed to be produced in gas loaded Ti and Pd samples. Autoradiography of D_2 loaded Ti disc targets have shown a number of hot spots indicating uneven distribution of tritium production in the near–surface region. On the whole the Trombay experiments have unequivocally confirmed the occurrence of cold fusion reactions both in Pd and Ti metallic lattices loaded with deuterium.

1. D_2O ELECTROLYTIC CELL EXPERIMENTS

Experiments to confirm the cold fusion phenomenon /1,2/ were initiated at Trombay during the first week of April 1989. A readily available commercial (Milton–Roy) electrolytic cell /3/ with Pd–Ag alloy tubes as cathodes and Ni as anode, originally meant for the generation of H_2 gas was adapted for the electrolysis of 5M *NaOD* in D_2O. Both a bank of BF_3 detectors embedded in paraffin and a proton recoil fast neutron detector (NE 102A) were employed to look for possible neutron emission. The first burst of neutrons was detected on 21st April 1989 when the cell current attained 60 amps. Later the current increased to 100 amps and the cell became overheated, resulting in the built–in trip circuit automatically switching off the power. This was followed by a big burst of neutrons approximately two orders of magnitude larger than background levels during a 5 minute interval. (The BF_3 counter measured 17,758 counts/300s and NE 102A scintillator 25,872 counts/300s as compared to average background values of ≈ 65 and 650 respectively). Fig.1 shows plots of the neutron counts data from the two detectors. From the efficiency of the neutron detection system measured using a standard Cf–252 source (≈ 2×10^4 n/s), it was surmised that ≈ 2×10^7 neutrons were emitted during that five minute interval.

A number of other D_2O electrolytic cells with Pd or Ti cathodes of different geometries and designs have also been set up at Trombay, but the current capacities of these cells are lower. Neutron and tritium production has been confirmed in all these cells as well (See Table I).

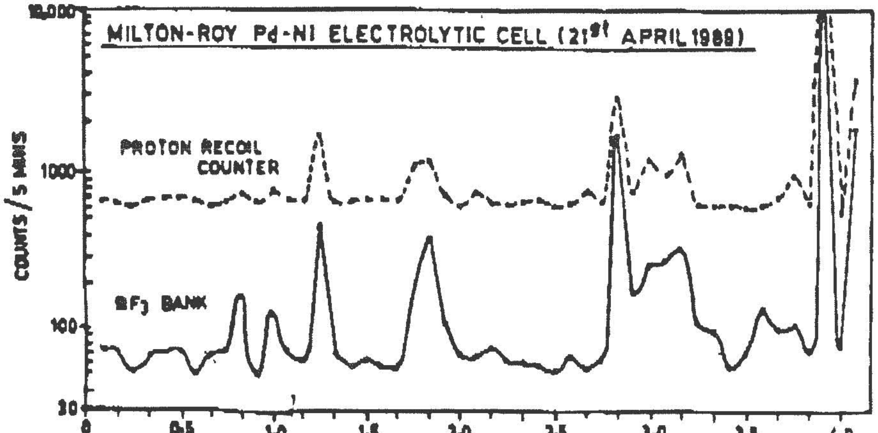

Fig.1. Neutron Counts Data From Two Detectors Using Milton–Roy Pd–Ni Electrolytic Cell (21st April 1989)

2. MEASUREMENT OF TRITIUM LEVELS IN D_2O ELECTROLYTE

The tritium levels in the D_2O electrolytes after a few days of continuous operation of the cells were measured by two seperate expert groups (belonging to the Isotope and Health Physics Divisions of BARC) who have been engaged in this type of work for over two decades. Well known liquid scintillation counting techniques applicable for low energy beta emitters were used, taking the following precautions: (a) ^{40}K free counting vials were employed to minimise background counts. (b) For higher count rate cases, 0.1 to 2 ml of sample was added to the scintillator while for low count rate samples ≈ 10 ml was used. In the higher concentration samples pH was reduced by diluting them with double distilled water, in order to minimise chemiluminiscence as well as quenching effects. Independently, whenever possible, these values were cross–checked with results obtained after "chemiluminiscence cooling". (c) Commercially available Instagel scinitillation cocktail was preferred over Dioxane as a solvent to minimise chemiluminiscence interference effects.

Prior to the commencement of electrolysis samples of the initial electrolyte were saved and counted along with each sample drawn during the course of the experiment. To compute the excess tritium produced in each run, the following points were taken into account: (a) Initial tritium concentration in the stock D_2O; (b) To be on conservative side the tritium that is carried away by the D_2 gas stream during electrolysis was neglected even though it is known that above 20°C the (T/D) ratio in the gas stream is comparable to that in the liquid phase and (c) Dilution effects due to periodic make–up of D_2O. Table I presents the tritium yields measured in some of the electrolytic cell experiments conducted at Trombay.

3. MULTIPLICITY SPECTRUM OF NEUTRON EMISSION

It is of interest to establish the multiplicity spectrum of neutron emission i.e. whether the neutrons are emitted individually (one at a time) or in sharp bursts of 10 or more at a time. The number of neutron pulses issuing from a bank of BF_3 counters (embedded in paraffin) monitoring the Milton–Roy electrolytic cell was totalled over 10 ms sampling intervals and stored in a personal computer. There were 1000 such sampling intervals during a real time of 5 minutes. Data was simultaneously also recorded from a paraffin encased bank of ^3He neutron detectors placed at a distance of ≈ 1.5 m from the cell, serving as a background monitor. The data accumulated during periods of significant neutron emission were statistically analysed to yield the probability distribution of neutron counts. It may be readily inferred from Table II which presents one such result, that neutron emission essentially obeys Poisson distribution. However it is also found that occasionally more than 10 neutron counts are registered in a single 10 ms interval. The background monitor has never yielded such high multiplicity events even over a one week period of continuous monitoring. This points to the occurrence of nuclear events wherein 100 or more

TABLE I: TRITIUM PRODUCTION IN ELECTROLYTIC COLD FUSION EXPERIMENTS

Sl No	DIVISION /GROUP	CATHODE MATERIAL /SHAPE	ELECT–ROLYTE	VOL. OF D_2O SOLN.	MAX. CELL CURRENT (Amps)	TRITIUM LEVELS (Bq/ ml) INITIAL	FINAL (10^3)	TRITIUM PRODUCTION (Bq) (10^6)	Atoms (10^{14})
1.	HWD/NtPD	Pd–Ag Tubes (M–R Cell)	5M NaOD in D_2O	250 ml	100	2.6	55.6	13.9	80
2.	"	"	"	"	"	10.0	4.4	1.1	6
3.	HWD/DD/ NtPD	Pd Sheets	"	1000 ml	65	2.0	7.0	7.0	40
4.	"	Ti Rod	"	135 ml	40	2.0	1.8	0.24	1.3
5.	ACD–(i)	Pd Cylinder	0.1 M LiOD in D_2O	45 ml	1–2	31.3	16.6	0.75	4
6.	ACD–(ii)	Pd Ring	"	65 ml	1–3	18.1	8.8	0.57	3

neutrons are emitted in a single sharp burst, probably under a 100μs in duration. Such occasional neutron "flashes" are also reported to have been observed by Menlove et al at LANL /4/.

4. GAS LOADED TITANIUM TARGET EXPERIMENTS

Following reports of neutron emission having been detected by the Frascati group /5/ with pressurised D_2 gas loaded Ti shavings, two variants of this experiment were carried out at Trombay. One group (Chemistry Division) followed the Frascati procedure with ≈ 20 g of cut Ti pieces and D_2 gas pressures increasing upto 50 bars. The temperature was cycled between 77 K and room temperature. The neutron detection system comprised of 24 ^{3}He counters arranged in a well like array and having a counting efficiency of ≈ 10%. The first neutron emission from this set up occurred on 3rd June when the temperature increased to ambient value from 77 K with simultaneous evacuation. The neutron count rate reached a peak value of 3900/40s as compared to initial background levels of 60 per 40s. The neutron emission phase lasted for about 30 minutes. The same charge was then subjected to temperature cycling between 77 K and 300 K leading to emission of ≈ 6.5 X 10^6 neutrons in all over a 7 hour duration. A similar neutron output lasting for ≈ 2 hours was recorded subsequently when the sample temperature was raised gradually with simultaneous evacuation. Fig.2. depicts the neutron yield variation measured during this run.

In a second variation of the gas loading experiment, small machined targets (discs, cones, cylinders etc) of Ti metal (mass between 0.2 to 1 g) were individually loaded with D_2 gas by heating them to 900° C in D_2 atmosphere at 1 Torr pressure and then switching off the power to the induction coil. D_2 gas was absorbed by the Ti target in the course of a minute or so during its cooling. The quantity of D_2 absorbed could be measured from the observed pressure drop. This corresponded to ≈ 10^{18} molecules of D_2 gas, indicating a gross (D/Ti) ratio of hardly 0.001. However it is believed that most of the absorbed D_2 gas is accumulated in the near surface region. Some targets did show statistically significant excess–over–background neutron counts during the one minute duration of gas absorption. A disc shaped Ti button loaded on Friday 16th June began emitting neutrons on its own, almost 50 hours after loading. It produced ≈ 10^6 neutrons over a 85 minute active phase. The background neutron counter did not show any increase in counts during this time.

TABLE II: MULTIPLICITY DISTRIBUTION OF NEUTRON COUNTS IN 10 ms INTERVALS

(Milton–Roy Electrolytic Cell: Friday 16th June 1989)

Time	BF$_3$ Counter Bank (Signal)															^{3}He Counter Bank (Background)		
(Hrs)	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*	13*	14*	15*	1*	2*	3*
18.55	124	21	4	1	–	–	–	–	–	–	–	–	–	–	–	2	1	–
19.00	54	9	1	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–
19.05	335	54	7	2	1	–	–	–	–	–	–	–	–	–	–	4	–	–
19.10	320	82	10	–	–	–	–	–	–	–	–	–	–	–	–	5	–	–
19.15	243	13	4	–	1	–	–		–	–	–	–	–	–	–	5	–	–
19.20	315	35	3	1	–	–	–	–	–	–	–		–	–	–	4	–	–
19.25	295	24	–	1	–	–	–	–	–	–	–	–	–		–	5	–	–
19.30	492	51	3	2	–	–	–	–	–	–	–				–	4	–	–
19.35	447	42	2	1	–	–	–	–	–	1	–	1	–	–	–	9	–	–
19.40	104	13	4	–	–	1	–	–	–		–	–			–	5	–	–
19.45	355	49	1	1	–	1	–	–	–	–	–		–	–	–	33	1	–
19.50	395	99	16	2	–	–	–	–	1	–	–	–	–	–		22	3	–
19.55	55	24	7	33	2	1	1	1	1	1	2	2	1	–	5	6	2	–

(*) Starred numbers represent the multiplicity of counts obtained in a single 10 ms interval. The respective frequency of occurrence (per 1000 gated intervals) is given in the corresponding column below.

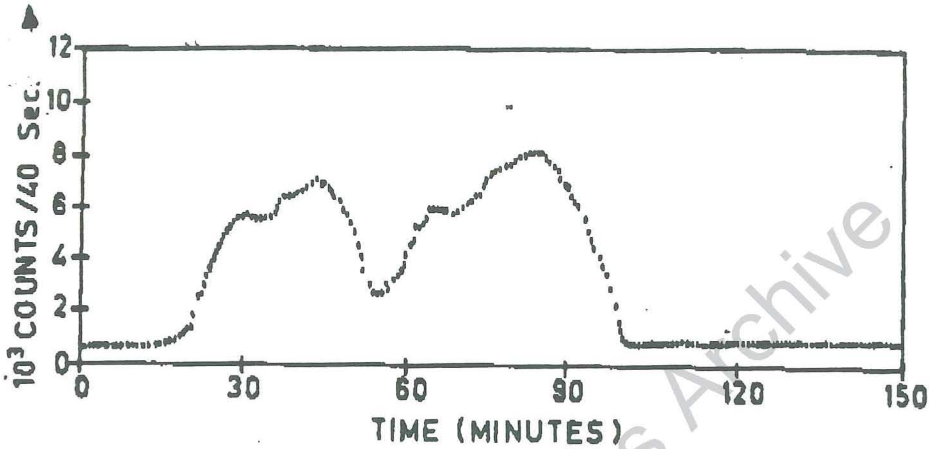

Fig.2. Neutron–Yield Variation During Desorption Mode: D_2O Gas Loaded Titanium–Experiments (7^{th} June 1989)

5. AUTORADIOGRAPHY OF DEUTERATED TITANIUM TARGETS

Since tritium which emits betas of 18 Kev (end point energy) has been found to be the primary product of cold fusion, it may be expected that autoradiography of deuterated Ti targets may give very useful information in the form of space resolved images. Deuterated Ti targets in which cold fusion reactions were suspected to have occurred were placed over a standard medical X–ray film and exposed overnight. On developing, the radiographs of deuterated Ti discs showed about a dozen intense spots randomly distributed within the disc boundary, besides a large number of smaller spots, especially all along the periphery forming a neat ring of dots (see Fig.3). Repeated measurements with the same disc target with exposure times varying from 10 to 40 hours gave almost identical patterns of spots, indicating that the tritium containing regions were well entrenched in the face of the titanium lattice. Spectral analysis of the X–ray emissions from such targets using a Si(Li) detector clearly showed the characteristic K_α(4.51 Kev)and K_β(4.931 Kev) peaks of titanium excited by the betas from tritium decay.

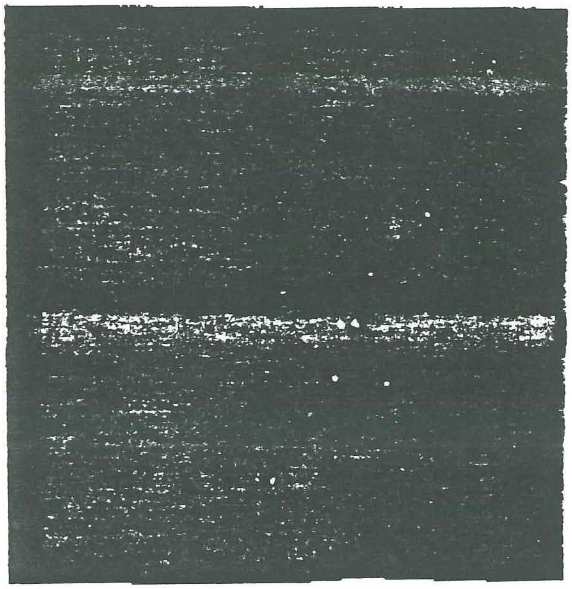

Fig.3. Typical Autoradiograph of a Deuterated Ti Disc Showing Regions of Tritium Concentration

6. SUMMARY AND CONCLUSIONS

Investigations of cold fusion phenomena carried out at Trombay during the first three months of the "cold fusion era", namely April to June 1989, have positively confirmed the occurrence of (d–d) fusion reactions in both electrolytic and gas loaded Pd and Ti metal lattices at ambient temperatures. Neutron emission has been observed even when the current to the electrolytic cell is switched off or in case of gas loaded Ti targets when no externally induced perturbation such as heating/ cooling/ evacuation etc is effected. The main findings of the Trombay investigations todate may be summarised as under:

(a) Tritium is the primary product of cold fusion reactions, notwithstanding the fact that the tritium, if any, entrapped inside the palladium electrodes has yet to be quantitatively assessed. Thus cold fusion may be characterised as being essentially "aneutronic" with a neutron to tritium channel branching ratio of less than 10^{-8}.

(b) Neutron emission both from electrolytically loaded Pd and gas loaded Ti is basically Poisson in nature i.e. the neutrons are emitted one at a time. However it is not clear whether the neutrons are generated in the (d–d) fusion reaction itself or whether it is produced in a secondary reaction involving the energetic protons or tritons. In this context it would be of interest to look for the possible presence of 14 Mev neutrons in cold fusion experiments.

(c) Occasionally nuclear events do appear to take place wherein over a 100 neutrons are generated in a single sharp burst. Viewed in the light of the branching ratio estimate of 10^{-8} noted above, this leads to the intriguing conclusion that a chain reaction involving as much as 10^{10} fusion reactions occurs within a time span of a 100 μs.

(d) Autoradiography of gas loaded Ti targets demonstrates in a simple and elegant manner not only the occurrence of cold fusion, but also the production of tritium. The estimated tritium to deuterium isotopic ratio in these targets is several orders of magnitude higher than in the initial stock D_2O and as such cannot be explained away on the basis of preferential absorption of tritium by the titanium as may be suspected. The existence of highly localised regions (hot spots) on the target surface wherein tritium is concentrated as well as the occurrence of spots all along the periphery of the disc, points to the important role of lattice defect–sites in the absorption process or in the accumulation of tritium following migration after its formation, at least in titanium.

The very high probability for the tritium branch in cold (d–d) fusion reactions would indicate processes of neutron transfer across the potential barrier as postulated by Oppenheimer over half a century ago /6/ and elaborated on more recently by Rand McNally /7/. If neutron transfer as envisaged by these authors does take place so easily, it may have many implications for the future of nuclear technology, for the deuterium nuclide might very well do the work which free neutrons do in present day fission reactors. In the context of the emerging energy production scenario, aneutronic fusion reactions such as this may give rise to new fusion technologies providing a cleaner energy source for the twenty first century.

ACKNOWLEDGEMENT

The work described in this paper has been carried out by many groups of scientists at BARC, Trombay. The details of the various experiments are under publication as a consolidated BARC report. I am grateful to many of my scientific colleagues for the illuminating discussions on various aspects of the work presented here. I wish to particularly thank Dr. M. Srinivasan for his help in the preparation of this paper.

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7 Rand McNally, Jr. J, Cold Fusion Prospects, Bulletin of APS, Baltimore Meeting, April 1983.

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-R.L. GARWIN-
14 SEP 89 15. 16

August 28, 1989

Subject: Chairman's July 20 Request for Summaries of Past and Present Cold Fusion Research and August 9 Request for Tritium Production Results

The following have been received to date from the following individuals in response to the above requests:

A. Bo U.R. Sundquist, Uppsala University (response to both requests)

B. W. Scheid, Giessen University (responses to both requests)

C. M.M. Broer, AT&T Bell Laboratories (response to August 9 request)

D. J. Eridon, Naval Research Laboratory (response to August 9 request)

E. Y.E. Kim, Purdue University (response to July 20 request)

F. A Schriesheim, Argonne National Laboratory (response to July 20 request)

G. M.A. Prelas, University of Missouri, Columbia

Since you will be receiving a number of these responses, I will be sending you a mailout just of them every week, and they will be identified in a continuing series.

Bill
William L. Woodard
Panel Secretary

Enclosures

082889.WLW

UPPSALA UNIVERSITET
Institutionen för strålningsvetenskap
Department of Radiation Sciences

Dr. William Woodard
U.S. Department of Energy
ER-6 3F
Office of Energy Research
1000 Independence Avenue
Washington, DC 20077-9381

Dear Dr. Woodard,

Uppsala 1989-08-16

In a letter from Dr. Huizenga I have been asked to report on the eventual tritium measurements we have made in connection with the study on the p-t channel in cold fusion of d+d. As we have made no measurements on tritium we have nothing to say. But of course the lack of protons is an indirect measure of tritium produced in cold fusion. For the sake of completeness I include a copy of the paper we published in May.

Sincerely,

Bo Sundqvist

Bo U R Sundqvist
Professor of Ion Physics
Uppsala university

Copy to prof. Jacob Bigeleisen

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VII

UPPSALA UNIVERSITET
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Professor John R. Huizenga
Co-Chairman Cold Fusion Panel
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US Dept of Energy
1000 Independence Avenue, S.W.
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USA

Dear Prof. Huizenga, Uppsala 1989-08-16

I have to-day (1989-08-16) sent Dr. Woodard the information you asked me to send him and now I will supply you with information on what we have done and what we plan to do.

We have studied the p-t channel in the thin foil experiment you find described in the included paper (accepted for publication in Physica Scripta, May 15). Since then we have continued the same type of measurements but with the same negative results. Since a month we have made no measurements.
Concerning the future we are interested in looking for explanations for the low level bursts of neutrons detected in some laboratories. In particular we are interested in the micro-crack ideas. An additional reason for that is my own main research interest in desorption of ions from surfaces, in particular insulators. As it is well known that an insulating surface created in vacuum emits secondary ions and electrons of considerable energy (keV energies) the "hot" deuteron explanation does not look too far fetched. Therefore we are considering an experiment to look for ejection of fusion products as a result of mechanical stress introduced to an electrolytically deuterium charged palladium sample.

Sincerely,

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On the observation of charged particles in cold fusion.

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Abstract

With the aim to confirm or reject the recent claim of observation of cold d-d fusion, an experimental effort has been made to try to observe MeV protons which should be emitted as a result of d-d fusion. Pd foils, thin enough to allow all protons produced to escape the foil, were electrolytically charged with deuterium. A Si(SB) detector was placed close to the Pd foil during charging in order to detect any protons emitted. The deuterium content was measured to be the expected 0.7 D per Pd. Monte Carlo simulations were made to estimate the detection efficiency of 3.02 MeV protons produced in the Pd foil.

The background in the experiment was so low that fusion rates considerably lower than those reported on by Jones et al could be detected. A number of experiments have been performed where the charging conditions were varied. In spite of that and the good sensitivity of the experiment no evidence for cold fusion has been found.

Introduction

Since the announcement of the Utah findings of evidence for cold fusion, a number of experiments have been performed with the aim to reproduce the original results of Fleischmann and Pons (1) and Jones et al (2). The two Utah findings are very different quantitatively but the common feature is the claim that cold fusion of light nuclei, in particular deuterons, has been observed as a result of electrolytic charging of deuterium in elements like Pd and Ti.

In the work of Fleischmann and Pons (1) the results are mainly based on calorimetric observations and large energy releases have been reported. The measurements indicate an energy release which, if due to fusion of light nuclei as claimed by the authors, implies fusion rates of the order of at least 10^{14} per second and cm^3 of Pd. Fleischmann and Pons report very dramatic effects, even melt down of electrodes and warn their fellow colleagues to perform experiments before consulting them. Also neutrons (a factor three above background) have been observed as a result of n,p reactions in the light water surrounding their electrolytic cells. The reaction was monitored by the detection of 2.2 MeV gamma radiation released. In addition tritium was detected. A striking feature of the Fleischmann and Pons experiment is that the neutron fluxes observed are incompatible with the energy release expected from d-d fusion, being of the order of 10^9 smaller than what could be expected from the branching ratios known from fusion at higher energies . LiOD was introduced in the electrolyte as a means to make the deuterated water a better conductor but it has been speculated that Li nuclei might also be involved in the production of nuclear energy.

In the Jones et al study (2) Ti was used as storage medium in addition to Pd and a complicated mixture of salts was added to the deuterated water. The observation of fusion was made by observing neutrons of 2.45 MeV from the $d+d \rightarrow n+{}^3He$ reaction. This was done with a fairly advanced, energy dispersive neutron detector which involves a technique to suppress gamma detection. These authors claim that they observe a weak but significant peak of neutrons due to cold fusion of deuterons. The highest fusion rate reported under the conditions specified in the paper is 1×10^{-23} per deuteron pair and second. This value is based on one single measurement which is 4-5 standard deviations above background. Most of the experimental runs gave values which are much closer to the background level and in fact the set of 13 experimental runs presented in ref 2 is only part of the total set of experimental runs (3). The experiments (four times more) which are not discussed are those which failed to give results.

The fusion rate given by Jones et al is at a much lower level (orders of magnitude) than those Fleischmann and Pons claim they have observed. In the two experiments reported there is also a clear difference in the interpretation of the experimental findings. While Fleischmann and Pons argue that it is a bulk effect , Jones et al claim that it is a surface process.

In view of the above it is far from convincingly shown that cold fusion occurs at all and, at the same time, of utmost importance to unambiguously show if this is the case or not . Apart from the exciting scientific concequences of the Utah claims the public speculations must very soon be guided by more solid scientific knowledge because of the dramatic concequences for the world energy supply if the claims made by the Utah groups should prove to be correct.

The energy released in a fusion process is excess energy of a compound nucleus and must be emitted in the form of radiation. The only direct way of determining if fusion has occurred is, therefore, to monitor the radiation released. Calorimetric measurements cannot distinguish between fusion energy and e.g. chemical energy and involves a number of corrections to give quantitative results.

Both experiments reported so far made use of electrolytic charging geometries involving bulk samples of Pd or Ti and only allowing for the observation of neutrons and possibly gammas from cold fusion reactions.

In this report we have therefore attempted to observe charged particles as a way of confirming or rejecting the occurrence of cold fusion in deuterium samples produced by electrolytic charging.

The various fusion reactions of interest are:

$$d + d \rightarrow n + {}^{3}He + 3.27\ (MeV);\quad T({}^{3}He) = 0.82\ MeV,\ T(n) = 2.45\ MeV$$

$$d + d \rightarrow p + t + 4.03(MeV);\quad T(t) = 1.01\ MeV,\quad T(p) = 3.02\ MeV$$

$$d + {}^{6}Li \rightarrow {}^{4}He + {}^{4}He + 22(MeV);\quad T({}^{4}He) = 11\ MeV$$

In addition to the channel given in the ^{6}Li case there are decay channels which lead to neutron emission. The reaction d+^{7}Li has one main channel leading to ^{9}Be and a gamma and will not contribute much, if anything, to the neutron production.

In order to try to explain the lacking flux of neutrons in the experiments by Fleischmann and Pons, radiationless deexcitation of the intermediate ^{4}He (formed in d-d fusion) and /or other ways in which the expected branching ratios in d-d fusion would be different from what is known from high energies has been discussed. However many of the explanations still involve emission of energetic charged particles.

Part of the results presented in this paper have been briefly reported at the MRS Spring Meeting, San Diego, April 24-28, 1989 and Workshop on Cold Fusion, Santa Fe, May 23-25, 1989.

Experimental arrangements

To be able to extract charged particles from a sample being charged with deuterium in an electrolytical cell, the direct way to arrange an experiment is to use a geometry with a thin electrode of the sample, as a window in the cell. We have chosen a foil of Pd following the Fleischmann and Pons study (1). The thickness of the foil (about 20 μm) was chosen so that protons of an original energy of 3 MeV will come out of the foil in an energy interval of roughly 1-3 MeV. The energy spectrum (if the reaction would be observed) will give information on at what depth in the sample the reaction has occurred due to the energy loss of a charged particle penetrating the foil. At the same time one can monitor if the reaction involving d-Li fusion occurs by observing alpha particles in the energy interval of roughly 0 to 11 MeV. For this reason the charged particles are detected with a Si(SB) detector of 100 µm thickness and an area of 100 mm^2 and in some of the runs 300 mm^2.

For obvious reasons the whole experiment is run under atmospheric pressure. The detector arrangement and the electrolytic cell is shown schematically in Fig 1.

Energy spectra are recorded by a conventional pulse height analyzer system and single energy spectra are collected. The background in the experiment is expected to be determined by pile up of electronic noise (single spectrum) and alpha particles from decay of radon in the surrounding atmosphere.

In order to protect the light sensitive detector the cell and the detector were kept in a dark box during the runs. In the last few runs in the series of experiments a larger detector was used and the detectors were cooled slightly (12°C)to reduce electronic noise (See Table 1)

The electrolysis of deuterated water and the cell used.

The appropriate geometry for this purpose was provided by an electrochemical permeation cell in which the anodic compartment was substituted for a cylinder holding the particle detector. Details of the electrochemical permeation cell were reported elsewhere (4). The electrolyte used was a 1 or 0.1 M LiOD prepared from metallic Li and D_2O (99.8 mole%). The Pd membrane was charged galvanostatically at $i= 100\ mA/cm^2$ using a Pt counter-electrode. In order to prevent the release of D_2 by desorption and/or catalytic oxidation with O_2 from air, the outer side of the Pd membrane was amalgamated with $HgCl_2$-solution, and in the later experiments coated with a layer of 4000 Å Au . In order to increase the rate of adsorbed D thiourea was added to the solution of electrolyte in the first experiment. The temperature of the solution was kept constant during the experimental runs (See Table 1), at 13±1°C. Some experiments have been carried out with the Pd membrane coated with black Pd on the charging side. The black Pd was electroplated from 2 % H_2PdCl_4 solution during 120 sec at 40 mA and has a roughness factor of about 20. In the last few runs (See Table 1) a new cell was used which has essentially the same geometry as the original permeation cell.

The concentration of deuterium (hydrogen) in the membrane was estimated in separate experiments carried out under similar conditions as the experiments described above. After the charging of the membrane (a current of 600 mA for 20 and 50 hours) the current was turned off and its open circuit potential vs an Pt/H_2 electrode was recorded during about 15 sec. Then the potentiostatic extraction method was applied in order to estimate the amount of deuterium (hydrogen) stored in the Pd membrane (5). The results were that the Pd/D and Pd/H ratios are close to 0.7. The dissociation pressure of both

ß-phase of Pd/D and Pd/H were within 10 and 100 atmospheres. These values were calculated from the open circuit potentials measured.
The diffusion coefficients measured suggest that after long time electrolysis the micro structure is strongly distorted.

Experimental procedure

The energy scale of the Si(SB) detector was calibrated using an ^{241}Am source giving alphas of about 5.47 MeV. An experimental run consisted of about 12-24 hours data collection with the detector facing the electrode and after that the detector was removed from that position so that it could not see the membrane for the same time.
The different experiments are described in the remarks of Table 1.
In Figs. 2A and 2B spectra with the detector in and off the cell position are shown. The radon level in the experimental area was measured to be 10 -20 Bq per m^3 . If one estimates the air volume between the detector area and the Pd foil to be 1 cm^3 there should be about 10^{-5} counts per second in the spectrum emanating from radon decays. .
The backgrounds measured as well as the countrate with the detector facing the charged Pd foil are statistically the same in all the runs made. The dominating background in the spectra are due to radon decays, however these decays mainly contribute to background outside the energy intervals of interest in this experiment.

Estimate of an upper limit to the fusion rate with the procedure used by Jones *et al.* (2)

Monte Carlo simulations of the geometrical acceptance of the detector and the energy distribution of 3.02 MeV protons assumed to be produced in the Pd foil have been carried out for the geometry shown in Fig. 1. Energy losses in the foil were calculated using the tabulated values of Ziegler (6). Particles leaving the foil with energies below 0.22 MeV were disregarded in the simulated detection process. The 4000 Å Au layer deposited on the "dry" side of the Pd foil and the 5 mm air gap between the foil and the detector give an energy loss below 0.2 MeVfor protons of all energies studied and was neglected.
The overall detection efficiency, ε_{det}, is then solely determined by the geometrical acceptance since the detection efficiency of protons was assumed to be 100 % in the energy interval considered.
The influence of the foil thickness was studied for the cases where the fusions are assumed to occur homogeneously in the bulk (Fig 3A) and on the "wet" surface of the foil (Fig. 3B), respectively. From the simulation results an optimal foil thickness, in terms of giving high count rates in both the bulk and surface cases, of 20 mg/cm^2 was chosen for the later experiments (Table 1).

As seen in Fig. 3 this foil thickness makes the interval 2-3 MeV representative for bulk processes and the region 1-2 MeV representative for a surface process.
Finally , increasing the detector area from 1 to 3 cm^2 for a 20 mg/ cm^2 foil was shown to yield factors of 3.5 to 4.0 in efficiency for the bulk and surface cases respectively.

A measured reaction rate R, corresponds to a fusion probability

$$\lambda_f = \frac{R}{\varepsilon_{det}} \cdot \frac{1}{n_{dd}} \qquad (1)$$

where n_{dd} is the number of d-d pairs in the foil. In accordance with Jones et al (2) we shall simply assume that $n_{dd} = n_d/2$ in the Pd lattice and that

$$n_d = \varepsilon_{(d/Pd)} \cdot n_{Pd}$$

where $\varepsilon_{(d/Pd)}$ is the deuterium to metal ratio. Hence

$$n_{dd} = \frac{\varepsilon_{(d/Pd)} \cdot n_{Pd}}{2} = \frac{\varepsilon_{(d/Pd)}}{2} \cdot \frac{A_{foil} \cdot t_{foil} \cdot \rho_{Pd} \cdot N_A}{M_{Pd}} \qquad (2)$$

where t_{foil} is the thickness of the foil
ρ_{Pd} is the density of Pd
N_A is Avogadro's number
M_{Pd} is the atomic weight of Pd.

With the typical parameter values
$\varepsilon_{det} = 0.03$
$\varepsilon_{(d/Pd)} = 0.7$
$A_{foil} = 6.6$ cm^2
$t_{foil} = 25$ µm
$\rho_{Pd} = 12.02$ g/cm^2
$N_A = 6.022 \times 10^{23}$ atoms/mole
$M_{Pd} = 106.4$ amu

(1) and (2) give

$$\lambda_f = 8.5 \times 10^{-20} R \text{ (fusions/deuteron pair} \times \text{sec)}$$

where R is measured in s^{-1}.

As can be seen in Table 1 twelve different runs have been made. In the remarks given for each run the differences are indicated. Fusion rates were calculated in each case according to the procedure above and in Fig. 4 the results of the twelve runs are displayed. The efficiency is based on the assumption of a bulk process and an integration of counts in the interval 2-3 MeV. All runs give a result which is zero within the statistical errors. We have added the results of the twelve runs statistically and the result is a fusion rate of

$\lambda_f = (-2.1 \pm 2.2) \times 10^{-24}$

If the same analysis is made for counts in the interval 1-2 MeV of runs 8-11 (See table 1) and assuming that a mono-layer of deuterons is formed on the front surface , with a surface density corresponding to the bulk density above, then the corresponding number is

$\lambda_f = (6.0 \pm 5.9) \times 10^{-19}$

This value illustrates that if fusion is a surface process the fusion rates one can observe in the experiment must be considerably higher than for a bulk process.In that case much larger d-d tunneling probabilities are needed to be able to observe the effect.
The measured "bulk" value can be compared with the value given by Jones et al (2). We have used the uncertainties in the reaction rate and the efficiency of the neutron detector stated by these authors to calculate an uncertainty in the fusion rate reported by Jones et al and their measured fusion rate then becomes

λ_f (Jones et al)$= (1.00 \pm 0.82) \times 10^{-23}$

Conclusions

We have demonstrated that the background level in the experiment is sufficiently low that one can observe fusion rates at least one order of magnitude lower than those observed by Jones et al (2). This is particularly so if the process is a bulk process. Several experiments have been performed where the conditions for electrolytic charging were changed. No deviations from the low background due to radon decays were observed. If we assume that the branching ratios are the same in cold fusion as those at higher energies we therefore see find no evidence of cold fusion for the experimental configuration used in the present work. This conclusion also holds for fusion in the ^{6}Li-d system.

Acknowledgements

Professors Stig Rundqvist, Arne Johansson and Bengt Karlsson are gratefully acknowledged for their valuable advice. Financial support

(R.B) from the Göran Gustafsson Foundation is gratefully acknowledged.

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Figure captions

Fig 1	The principle of the experimental set up with the detector and the cell. A= Ampere meter, V= Bias supply, W= working electrode and C= Counter electrode.
Fig. 2A	The resulting Si(SB) energy spectrum of run 4. The collection time was 24 hours.
Fig. 2B	The background spectrum in run 4. The collection time was the same as in the spectrum above.
Fig. 3A	The simulated proton energy spectrum for a bulk process occurring homogeneously in a 20 mg/cm^2 Pd foil.
Fig. 3B	The simulated spectrum for a surface process.
Fig. 4	The fusion rates measured for the twelve runs. The detector efficiency used is based on the assumption of a bulk process and integration of counts between 2 and 3 MeV. For comparison see simulated spectrum in Fig 3A. For explanation of the run labels see table 1.

Table 1

Run no	Remarks (Only changes compared to the earlier run are indicated)
1	Pd foil (20µm), Thiourea added, Hg film, 1 M LiOD
2	Same as 1
3	New laboratory, new Pd foil (15µm), 4000 Å Au as protective film, 0.1 M LiOD.
4	Black Pd deposited, i e 20 times larger active area.
5	Same as 4
6	More Pd deposited.
7	New Pd foil (15µm), new cell, new larger (300 mm^2) area detector, detector cooled.
8	Same as 7 but the large area detector replaced by the smaller detector. Electronics replacements.
9,10	Same as 8
11,12	A new 300 mm^2 detector was used

Each run lasted 20-40 hours and was followed by a background run of the same length.

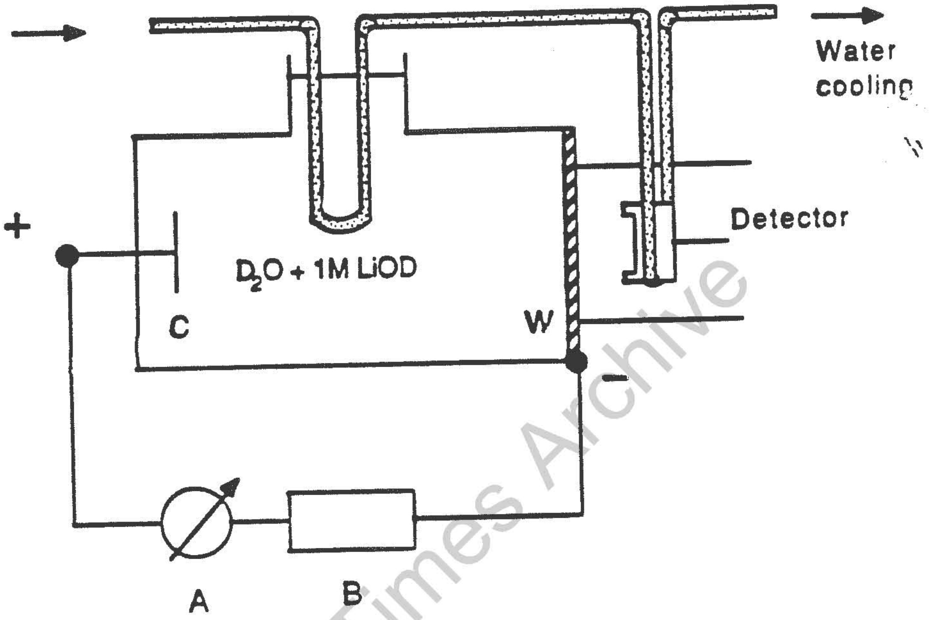

Fig. 1

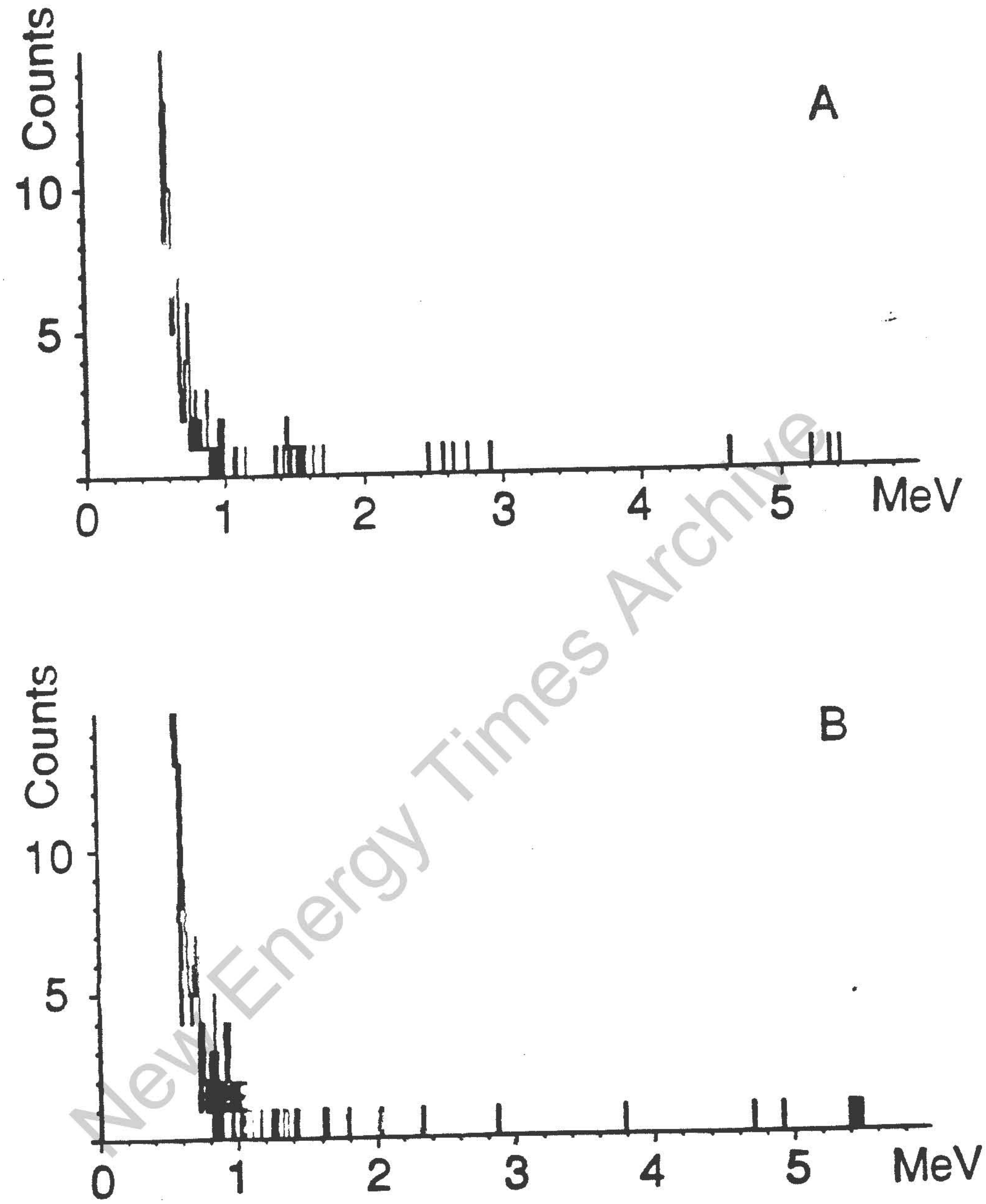

Fig. 2

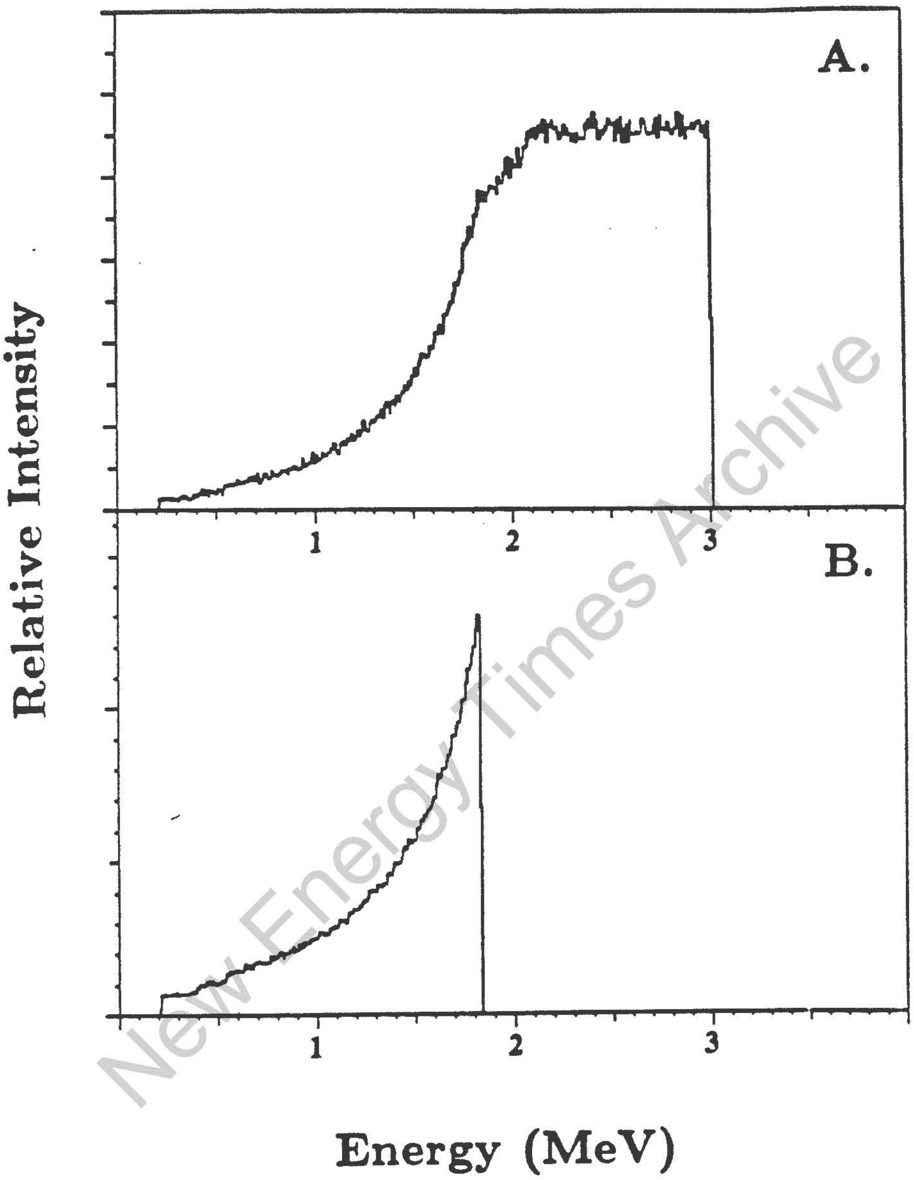

Fig. 3

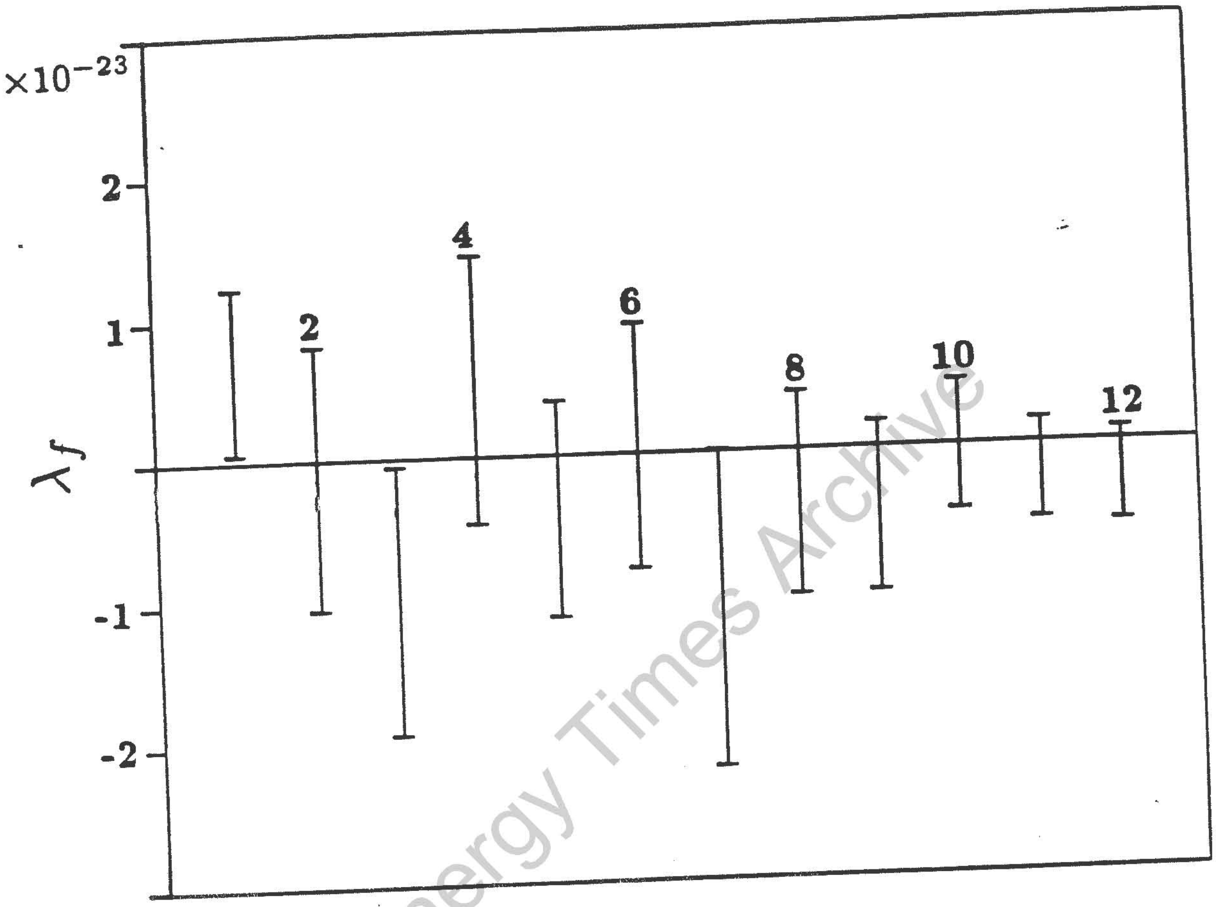

Fig. 4

Prof. Dr. Dr.H. Hora
Prof. Dr. W. Scheid

15/8/89

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Ref.: Summary of a project for the ERAB

ION PLASMA MODEL FOR EXPLAINING COLD FUSION

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For an explanation of the preliminary observations of cold fusion we developed a model where the deuterium after incorporation into the titanium or palladium metal lattice is ionized and the electrons trapped at lower energetic levels, e.g. to fill up an incompletely occupied lower electronic shell. The ions are considered like freely moving plasma particles between the metal ions and the electrons. The rather exotic plasma of very high density and very low temperature should provide the probability of fusion reactions for the statistically rare cases with deuterium ion distances of one tenth or less of the ionic distance in a deuterium molecule. This scenario is necessary for explaining a fusion rate of one reaction per cm^3 as measured at room temperature.

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The model would immediately explain the microsecond bursts of 1000 or more neutrons measured as a subsequent reaction in the deuterium plasma. As a provisional possibility for future considerations the model would contain also a temperature dependence with a power of 10 to 15 as known from the high temperature fusion reactions /1/ such that heating effects - whatever their cause may be - could then be explained. Any more detailed studies need an extensive elaboration of the experimental facts on cold fusion. Whatever their outcome will be, the plasma model at all is worthwhile to be used for the study of the deuterium solution in palladium and of similar problems. Up to now the plasma model has been applied to the surface tension of plasmas and was extended to a new straightforward theory of the surface tension of metals /2/ and even of nuclei /3/.

An extensive paper on this plasma model for cold fusion was presented at the ICNES Karlsruhe, July 4, 1989 /4/.

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/4/ H. Hora, G.H. Miley, L. Cicchitelli, A. Scharmann and W. Scheid "Nuclear Fusion in Host Lattices Discussed by the Model of Nondegenerate Positive Hydrogen Isotope Ion Gas", 5th Intern. Conference Emerging Nuclear Energy Systems, Karlsruhe 3-6 July 1989, G. Kessler, ed. (World Scientific, Singapore, 1989).

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Enclosure

5th Intern. Conf. Emerging Nuclear Energy Systems, Karlsruhe 3 - 6 July 1989,
G. Kessler Ed., (World Scient., Singapore 1989)

NUCLEAR FUSION IN HOST LATTICES DISCUSSED BY THE MODEL OF A NONDEGENERATE POSITIVE HYDROGEN ISOTOPE ION GAS

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For the reported observation of neutron emission due to cold nuclear fusion of deuterium in titanium we discuss a model for the electrons and ions of the hydrogen isotopes in the host lattice. The electrons are more locally bound to states of unfilled shells with stronger energetic levels while the positive ions form a nearly ideal and non-degenerate gas of plasma of very high density and very low temperature. Arguments for this model with respect to the electrons are the quantum theory of compressibility including the electrostatic atom model. This result and measured electric conductivities support the gas model for ions. The discussion of such a model is of interest for the fusion reactions. The reported low level of measured fusion energy is discussed and conditions which may permit an increase of energy are given. Fusion reactions would be describable by the volume ignition model.

INTRODUCTION

The nuclear fusion reaction of deuterium incorporated in the lattice of titanium has been reported with details of extensive counting of fusion neutrons which roughly agree under different conditions [1,2,3]. Several surface modifications of the titanium cathodes of the electrolysis by iron contamination were investigated [1]. The reported numbers of neutron counts seem to be sufficient above the level of the background noise especially after reducing the cosmic ray level [2]. It is important to note that each neutron count reported by Jones et al. [1] consists of more than 100 neutrons similarly to the large bursts of neutrons reported before [4].

The technique of the fusion neutron measurement is based on the long years experience of instrumentation for myonic catalyzed fusion [5]. A very sensible detector was used to determine the large number of neutrons per burst [3].

We base our discussion on the statement [1,2,3] that the measured reaction rate of the deuterium-deuterium reaction reaches at room temperature in the deuterium filled (or possibly saturated) metallic host crystal (titanium, paladium or similar) a value of

$$10^{-20} \text{ reactions per second.} \qquad (1)$$

The density of the deuterons may be much lower than the value of

$$n = 10^{23} \text{cm}^{-3} \qquad (2)$$

as seen from the iron contamination [1].

This reaction rate is nevertheless remarkable and understandable only by comparison with the myonic fusion where instead of an electron a myon is used in a hydrogen molecule. Despite the Coulomb barrier of more than 800 eV, the fusion reaction occurs within very short times of less than 100psec even just before the myons in the molecule have dropped to fundamental quantum numbers of 5 or 6. In lower states the muon decays and disappears [6]. The fusion reaction is then determined by either a cross section, which is by many orders of magnitude larger than the one for hot fusion extrapolated from the measured values at keV energy and more [7], or by a tunneling process which may have occured. The earlier discussed modifications of nuclear potentials as expected from pycno-nuclear reactions [8] may be of importance. The then necessary very high densities of 100,000 times of the solid state let come the deuterons into ranges of the relative distance as in the case of myonic fusion.

The aim of the following discussion is to present a model for the state of the hydrogen isotopes in the metal lattice where attention is given to plasma properties. In solid state theory the application of a plasma model is not restricted to the most successful plasmon model only. Very recently a model of the just discovered surface tension of plasmas [9] was extented to the degenerate electron gas in a metal lattice, and an immediate reproduction of the measured surface tension of metals was reached [10]. This plasma model immediately leads to the surface energy of nuclei [11] by use of the relativistic Fermi energy of the nuclei. However, no direct analogy to the plasma state of quarks [12] at shock produced [13] increased nuclear densities is made.

2. PROBLEMS OF A CRYSTAL MODEL

The phenonemon of very high concentrations of hydrogen in metals like platinum, palladium or titanium was studied by a very large number of research papers in chemistry since the early last century. A large number of papers was devoted to the properties of heavy hydrogen since the thirties after heavy water was discovered.

The recent observations [1,2,3] and the analogy to the myonic fusion were discussed in terms of a high value of the effective electron mass such that individuals of these electrons would cause a binding of a positively charged molecule as done by the myons for two deuterons. The higher effective mass of the electrons would cause a reduced molecular dimension and hence a shorter distance between the deuterons favouring the nuclear fusion.

This model seems not easily to be justified at least from the point of view of the usual effective electron mass which can deviate by large factors mostly to smaller values than the vacuum value of the mass in semiconductors and metals (see Appendix A in Ref.[14]).This type of effective mass follows for electron states in a periodic potential of a (large) number of positive crystal ions where the well known bands of permitted and forbidden energies determine the effective mass. The presumptions of this model are basically contrary to the localized states of electrons in molecular binding. Therefore, the hypothesis of large effective electron masses cannot be derived directly from such considerations.

In order to explain the increased cross sections in the case of myonic fusion and of the reported cold fusion in titanium or palladium cathodes at electrolysis, deviations of nuclear potentials were discussed by several authors though the resulting modifications of the usual properties are not sufficiently strong to explain the reported observations. A combination with the long years known deviations of nuclear potentials in the case of the pycno-nuclear reactions [8] may be of interest.

We may indicate here that any binding mechanism of the electrons by crystalline phase structures or coordination geometries should at least not correspond to the states of valence or conduction electrons. This can be concluded from the fact that the density e.g. of the palladium does not change strongly, when hydrogen or its isotopes are incorporated,and may be seen from a model of the compressibility κ of condensed materials determined by the Fermi quantum pressure (see Eq.1.12 of Ref.[15]):

$$\kappa = 6m_o/(h^2 n^{5/3}). \qquad (3)$$

Here, m_o is the electron mass (possibly modified as effective mass), h is Planck's constant and n is the electron density of the conduction electrons in metals or of the valence electrons in non-metals where a factor two has to be multiplied if two electrons are in the same electronic quantum state with different spins.

Eq.(3) is derived from principles contrary to Madelung's theory of compressibility. Since the density is not yet a quantum mechanically derived quantity in solids, only the empirical densities can be used for comparison. The compressibilities agree well with measured ones over the whole range of three orders of magnitudes (Fig.1.2 of Ref.[15]).

As seen in the electrostatic atom model (Sect.2.3 of Ref.[14]) the compensating electrostatic energy against the quantum energy has been included into the model of the compressibility and may be affected by second order only if electronic states of lower shells influence the mentioned conduction or valence electrons. This is the reason that the electrons of the hydrogen isotopes after being incorporated in the mentioned metals are not in a state like the conduction electrons but in a tighter bound energetic state.

3. ION GAS MODEL

We propose a model which describes the incorporated atoms as ionized and the electrons as bound in lower level electronic states in the crystal atoms. The reason for the lower energetic levels is explained in the previous section by the fact that the compressibility does not change much in connection with the density. Therefore, these elements which are elements of the eighth group of the periodic table or elements near the rare earths should have a strong affinity to put electrons into incomplete electronic shells. If the ionized state of the incorporated hydrogen ions in the metal lattice is providing an appropriate positively charged background, the electrons from the incorporated hydrogen isotopes are energetically allowed to fill up states of incompletely filled lower electronic levels.

It is evident that these states correspond to a higher energy gain than the ionization energy of the hydrogen (perhaps 15 eV or more) such that an exothermal process of the incorporation into the metallic lattice can be understood. The amount of energy transferred to the electrodes at this electrolytic processes is one of the points to which attention is now given in a more quantitative way than in the numerous experiments before and it may not only be due to a trivial neglection of reaction energy of oxygen with hydrogen when leaving the crystal. It should be noted that the suggestion of stronger energetic levels for electrons of the incorporated hydrogen isotopes due to unfilled electronic shells of the metals was already published in 1937 [16].

Let us consider the positive ions of the hydrogen isotopes in the host crystal. They form an ideal ionic gas of such high densities like a solid state, but of such low temperatures as the room temperature. Fully ionized gases of such densities and temperatures are never possible outside the lattice by the well known reasons of the constitution of atoms and molecules at usual densities (not to talk here about plasma states of metallic hydrogen at pressures of more than 10 million atmospheres at room temperature).

Such a non-degenerate gas of hydrogen isotopes with high density and low temperature provides ideal conditions for fusion reactions despite the low temperatures. Because of the very high density the number of ions with extraordinarily high energy is then considerable. By taking a longer time for the reactions instead of the short psec duration for myonic fusion reactions, the observed and otherwise estimated numbers of the reactions as given in Eq.(1) should well be possible.

A more quantitative study of the collision probabilities has to be done. Tunneling or pycno-nuclear modifications of cross sections or why the low energy hydrogen isotopes probably permit a preference of fusions with a release of the reaction energy as gammas, direct H-D reactions and/or H-B(11) or H-*Li*(7) or *D*-Li(6) reactions with completely different *probabilities than known* from the beam interaction experiments with more than 100 eV energy, all these questions are very important to be studied.

Theoretically, the mentioned plasma model for the nuclei of the hydrogen isotopes in the host crystals should indeeed provide the possibility to estimate the fusion rates. The fact that this state of incorporation - even if no fusion reactions would occur - *has not* been studied before, despite the large number of papers of hydrogen in titanium or palladium and analogeous cases, is indeed one of the necessary tasks in physics. The novelty is then that the new broad stream of plasma physics and solid state physics have to be added.

One minor argument in favour of this plasma state is the long known measurement of the electrical conductivity of deuterium in palladium [17] which is increasing with the deuterium concentration. This can be understood as following: While the electrons for the conductivity remain at a constant density and despite the fact that the number of conduction particles is increased by the added positive plasma ions, the counter streaming charges will produce a higher level of collisions such that the electric conductivity decreases. In this context one should remember the research of the physics of proton conductivity in solids which field may well profit from the models of plasma theory as mentioned here.

4. CONCLUSIONS

The following suggestions will be interesting if the results [1,2,3] will be experimentally extented and the fusion gains of the order of Eq.(1) are further reproduced. This would support the conclusion of the preceeding paragraph that the hydrogen isotopes incorporated into titanium, palladium and similar elements may produce a plasma state for the positive ions of most remarkable properties and that this state deserves a very special study for basic reasons and for numerous applications in physics and chemistry.

In proposing the direction of further experiments, the plasma ion model would be the basis for exploring the three-particle collision process proposed by Becker [18] since the exotic ion plasma of such high density and low temperature provides high probabilities for three-particle collisions. Furthermore, the observation [3] of bursts of 100 and more fusion neutrons could be explained by the ion-plasma model since the statistically produced energetic products of the first reaction (produced in tunneling, resonance or pycno-nuclear processes) may cause an avalanche of reactions after collisions with other cold ions.

Furthermore the plasma model of low temperature and high density may be involved in the experiments of gas discharges of high density deuterium compounds with nitrogen [19] where an initially produced plasma state leads to the production of similar fusion neutrons.

The observation of high rates for fusion reactions at temperatures in the range of a few hundred Kelvins may be an indication of a high power dependence of the temperature for the cold fusion similar to the T^n-increase of fusion with n=10 to 15 in low temperature ranges of usual hot fusion [7,20] as long as the solid state structures of the host lattice are conserved. The reaction would then behave like volume burn or even volume ignition [21] for the energy production by fusion.

In support of this plasma model for the deuterium ions, we mention the result by Tajima et. al. [22] that ionic distances of 0.1Å to 0.7Å increase the reaction probability bei 10^{50} compared with the distance of deuterium in a molecule. In view of the very high density of the ions in the exotic low temperature plasma, the probability due to the fast range of the Maxwellian energy distribution is rather high per volume for distances of 0.1Å and less - though relatively low per particle - and may explain the measured fusion neutrons.

Acknowledgment: Support of this work by the Heinrich and Elisabeth Heraeus Foundation is gratefully acknowledged.

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August 17, 1989

Mr. William Woodard
Secretary, Cold Fusion Panel
ER-6, 3F-043
US Dept. of Energy
1000 Independence Ave, SW
Washington, DC 20585

Dear Mr. Woodard:

In response to Prof. Huizenga's letter of August 9, 1989 regarding the issue of tritium production during cold fusion experiments, please find below the answers to the specific questions, as far as our own experiments are concerned.

1. The D_2O in our neutron detection experiments in deuterated Pd rods was obtained from Aldrich Chemical Company, Milwaukee, WI: cat. no. 15188-2, with a nominal 99.8 atom % D concentration.
2. Our electrolytic cells were made from borosilicate glass, approx. 5 cm diameter x 10 cm height. The cells were sealed with teflon stoppers and the generated O_2 and D_2 were released through a single bubbler trap. The volume of the D_2O is approx. 200 cm^3. The Pd rod emerged from the solution (0.1 molar LiOD in D_2O) and through the seal. The anode was a Pt wire cage, coaxially positioned around the Pd rod.
3. Our cells were run in a constant current mode with current densities between 60 and 70 mA/cm^2 (corresponding potentials: 5-6 V).
4. Pure D_2O was added typically once every two days during which period the solution level would drop approx. 0.5 cm.
5. The goal of our experiments was the detection of neutrons; no tritium measurements were carried out.
6. During a four week measurement we observed < 0.007 neutrons/sec/g Pd. This corresponds to a fusion rate of $< 2.2\times10^{-24}$ (ddn) fusions/dd pair/sec, assuming a volume effect.
7. No quantitative measurement of any "excess" heat was carried out; the temperature in the cells was monitored with a mercury thermometer for any possible gross thermal effects.
8. No investigation of the location of any tritium sources in the building was made, since no tritium measurements were carried out in our experiments.

Finally, I attach a copy of our neutron work, which has been accepted for publication as a Rapid Communication in Phys. Review C (Nuclear Physics).

Sincerely Yours,

Matthijs M. Broer

encl.
cc.: Professor J. Bigeleisen, SUNY, Stony Brook, NY

Accepted for publication:
Phys. Rev. C (Rapid
Communications)
8/89

Search for Neutrons from Deuterium–Deuterium Nuclear Reactions in Electrochemically Charged Palladium

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Abstract

We report on a search for neutrons from dd fusion in Pd rods loaded electrochemically with deuterium. In a four–week measurement we observe <0.007 n/sec/g Pd, compared to $2.6\text{x}10^3$n/sec/g Pd, claimed recently by Pons, Fleischmann, and Hawkins. Our result implies $<2.2\text{x}10^{-24}$ (ddn) fusions/dd pair/sec, as compared to $\sim 10^{-23}$ (ddn) fusions/dd pair/sec observed by Jones et al in a Ti electrode.

PACS: 25.70.Jj, 29.30.Hs, 29.40.Mc

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The recent reports by Pons, Fleischman, and Hawkins[1] (PFH) and Jones et al.[2] of the observation of neutrons from palladium (titanium in Jones' case) electrochemically loaded with deuterium has stimulated intense interest in the verification of this process, and in the entire possibility of "cold nuclear fusion". In this paper we report our search for neutrons from the electrochemically loaded Pd–D system at room temperature.[3] We set an upper limit on the deuteron–deuteron fusion rate of 2.2×10^{-24} (ddn) fusions/dd–pair.sec, with ddn indicating the neutron producing branch of dd fusion. This is *five orders of magnitude below* that reported in PFH and approximately a factor of five below that reported by Jones. One unique aspect of our experiment, is the use of the high energy portion of the gamma ray spectrum from thermal neutrons captured by Na and I in a NaI(Tl)–spectrometer system. Such a method renders the detection system relatively insensitive to ambient natural radioactivity and results in enhanced sensitivity for thermal neutrons. We also report a quantitative nuclear reaction analysis of the deuterium loaded Pd rod to estimate the amount of absorbed deuterium.

We investigated the possible neutron emission from three Pd rods: two wires (0.125 cm diameter by 10 cm long) were mounted separately and parallel to each other in one electrolysis cell. A second cell contained a 0.4

cm diameter x 10 cm rod. Both cells were made from borosilicate glass (Pyrex, approx. 0.2 cm wall thickness) and sealed with Teflon or a rubber stopper to prevent D_2O exchange with atmospheric light water. The electrolytically generated O_2 and D_2 were released through a single bubbler trap, filled with silicone oil. The Pd cathode emerged from the electrolytic solution and then through the seal on the top for electrical connection. In the case of the cell with the two wires, the wires were strapped to a glass rod to prevent electrical shorting caused by shape distortion due to the deuterium loading. The submerged length was 6.9 cm for the 0.4 cm rod and 9 cm for the two smaller wires. The anode was a Pt wire (0.076 cm diameter), coiled onto a 2 cm glass tube cage. This cage was positioned coaxially with the Pd cathode and one of the glass support tubes was fed through (with the Pt wire inside) the top seal for electrical connection.

The temperature in the cells was monitored with conventional mercury thermometers. Since the purpose of this experiment was the detection of neutrons and not a quantitative measurement of any possible "excess" heat effects associated with cold fusion, these thermometers only served to indicate any gross thermal excursions. The electrolytic solution in both cells was nominally the same as that used by PFH: 0.1 molar LiOD in D_2O (99.8 atom % D) with the LiOD obtained by adding Li_2O ($^6Li/^7Li$ ratio unknown) to the heavy water. Both cells were operated in a constant-current mode (separate power supplies) with current densities of 63 and 70 mA/cm^2 for the 0.4 cm rod and the 0.125 cm wires, respectively. Corresponding applied cell potentials varied between 5 and 6 V. The current density values were chosen as an intermediate value of those used by PFH, at which they claimed to have observed a significant neutron flux ($4x10^4$ s^{-1} for a 0.4x10 cm rod).

The Pd wires and the rod in this experiment were prepared in different ways. The two wires were cut from an available wire spool (99.95% Pd), which had been drawn to its final diameter from an ingot. One of the wires was subsequently annealed at 900 °C for approx. 1 hr in flowing N_2. The rod was cast from Pd powder (99.95% Pd), which was melted under Ar in a radio frequency heated BN crucible and subsequently cold rolled to its final diameter. The rod was then annealed as described for the wires. Finally, both wires and the rod were cleaned with a light mechanical polish (sandpaper). After approximately one day's exposure to room atmosphere, they were inserted in the D_2O/LiOD cell electrolyte.

In this experiment the neutron detector was a single NaI(Tl) scintillation crystal (12.5 cm diameter x 12.5 cm length), completely surrounded with polyethylene moderator, as shown in Fig. 1. The two cells were placed inside this moderator "house" with 5 cm polyethylene between the detector and the cells. Lead blocks were positioned outside this "poly house" to reduce undesired γ background and approximately 5 cm thick borax containing boxes were placed outside the lead shield to absorb any external neutrons. Any neutrons resulting from dd fusion reactions inside the Pd rods are moderated to thermal energies in the polyethylene blocks. The thermal neutrons then either yield a 2.225 MeV γ-ray from the (npγ) capture reaction in the polyethylene or a nearly continuous spectrum of high energy γ's in the range 3.5–7 MeV from thermal neutron capture by ^{23}Na and ^{127}I within the detector.

The advantage of detecting in this high energy region, rather than directly at the 2.225 MeV line, is the significantly reduced background, which arises mainly from natural radioactivity. This can be seen clearly in Fig. 2b, which shows a typical pulseheight spectrum from the NaI detector. Three lines, at

2.120, 2.204, and 2.447 MeV, appear in this 2.225 MeV region and are associated with the ^{238}U decay chain. In addition, background lines at 2.614 MeV (^{232}Th chain), at 1.764 and 1.847 MeV (^{238}U chain), and the ^{40}K line at 1.460 MeV were observed. The highest energy γ–ray from ambient natural radioactivity is 3.35 MeV. Thus at higher energies (>3.5 MeV) the spectrum is free from these radiation sources except for very weak high energy fission γ–rays and a very low level of α–rays from U and Th decay in the crystal itself. Thus, in contrast to the use of 2.2 MeV γ's as an indication of the (npγ) reaction, our method practically eliminates the possibility of mistaking a background γ–ray for a neutron signal.[4]

The residual background above 3.5 MeV is nearly all due to cosmic ray muons passing through the crystal. In order to reduce this background, two plastic scintillators were installed above and below the NaI detector. Events detected in the NaI crystal were gated in an anti–coincidence mode by pulses from the two plastic scintillators. The gated output for a fixed lifetime, typically 1800 sec, was analyzed and stored in a multichannel analyzer. The spectral data (0–7 MeV) was periodically transferred onto a hard disk of a personal computer. From this experimental database the temporal behavior of the gamma ray intensities in any region can be accessed and examined; regions of particular interest are those around 2.2 MeV (region R2) and the n–signal range 3.5–7 MeV (region R1).

The neutron detection efficiency was measured with a Am–Be source with a nominal neutron flux of 6x10^{4} s^{-1}. After placing this source in a identical ^{7}LiOD/D$_2$O cell in the same position as the electrolysis cells, the calibration spectrum was obtained (Fig. 2a). This shows clearly the 2.224 MeV line due to the (npγ) capture, as well as the broad band signal from the reaction of thermal neutrons with ^{23}Na and ^{127}I. The line at 4.4 MeV (and part of the lower energy single escape line peak at 3.9 MeV) are due to (α,nγ) reactions in the source and from the reaction ^{12}C(nn'γ) in the polyethylene by neutrons of energy > 4.4 MeV. This feature is not expected from 2.5 MeV fusions neutrons. A nominal neutron detection efficiency of 0.015 was obtained from the counting rate in R1, with the source in place, divided by the neutron flux from the Am–Be source. It must be noted, however, that a substantial fraction of the neutron flux from this source ranges in energy up to 8 MeV, significantly higher than 2.45 MeV, the energy of dd fusion neutrons. The higher energy neutrons are moderated less efficiently and thus contribute less to the signal in R2. The value of 0.015 employed in this work should therefore be considered a lower limit to the neutron detection efficiency actually relevant to dd fusion detection.

The 0.4 cm rod was charged for 33 days during which the neutron detection system was operative. At the end of this period the current was discontinued. The sample was allowed to outgas for 24 hours in an open, silica container which was flushed with dry nitrogen gas at atmospheric pressure. After this period the 0.4 cm rod was removed and stored in liquid nitrogen. Since the diffusion coefficient of D in Pd at 77K is approx. 10^{-17} $cm^2.s^{-1}$, vs. ~$3x10^{-7}$ $cm^2.s^{-1}$ at 300K in the β–phase of Pd–D (using the known activation energy[5–9]), storing at 77K assures retention of the remaining deuterium.

It was noticed upon removal of this rod from the electrolysis cell that the submerged section had clearly expanded and that the rod thus had a "wine bottle shape". The submerged part was approx. 0.45 cm in diameter, while the unsubmerged part retained the original 0.40 cm diameter. The rod was removed from the liquid N_2 for about two hours for dicing into discs for subsequent analysis. This process consisted of using a diamond saw to cut three, 0.15 cm discs from both ends of the rod. The different material properties of the deuterated and undeuterated portions were already noticed at this stage, as the deuterated portion cut much more slowly and unevenly. This clearly reflects the brittling effect of the deuterium on the Pd.

The deuterium loading was examined via nuclear reaction analysis using the d(^{3}He,p)α reaction, a standard ion beam analysis technique[1] . The resulting spectrum is shown in Fig. 3 and indicates a strong proton and alpha particle signal, indicative of a large deuterium concentration. Since the cross section for the analysis reaction is about 10^{-3} of the ^{3}He elastic (Rutherford) scattering reaction, it is immediately obvious that the deuterium concentration is comparable (within an order of magnitude) to the Pd concentration. It should be noted that the measurement was carried out at the center of the disc indicating that the deuterium had diffused through the entire cross section of the rod during the electrochemical loading time. This diffusion (charging) time to reach the rod center is $\Delta t \simeq R^2/D$, with R the radius of the rod and D the diffusion coefficient of deuterium in Pd. For R= 0.2 cm and D= 3×10^{-7} $cm^2.s^{-1}$ (at room temperature), this time is 1.5 days. Analysis of the portion of the rod which was not submerged gives no indication of a deuterium signal. The absence of deuterium 4 cm above the loaded area is consistent with a diffusion length of only 0.85 cm for the sample at room temperature for four weeks. The analysis of the nuclear reaction data is complex since the experiment probes through the penetration depth of the ^{3}He (about 2 μm) with a reaction cross section strongly varying with ^{3}He energy. Furthermore the first few microns have lost deuterium due to out–diffusion into the atmosphere during the two hours of exposure for cutting and analysis (corresponding diffusion length ~460 μm). Nevertheless the extracted D/Pd ratio is 0.38 which is consistent with typical maximum loading values[5,9,11] and out–diffusion during the cutting period. Despite some uncertainties in this analysis, substantial deuterium loading at the center of the 0.4 cm Pd rod is clearly demonstrated.

As mentioned previously, during electrolysis the γ–ray flux both at the 2.2 MeV region (region R2) and in the region between 3.5 and 7 MeV (region R1) was measured. Fig. 4a shows the count rate with both cells inside the poly "pit" up to 14 days after the start of the experiment. At day 16 the current through the cell with the two wires (cell 2) was discontinued, the cell removed and the shielding temporarily disturbed in order to facilitate the repositioning of the cell with the 0.4 cm rod in front of the detector. As can be seen in the figure this resulted in a small but clearly observable spike in the counting rate in the 2.2 MeV region due to enhanced exposure to ambient room background, clearly illustrating the danger of relying on this spectral region to determine any low level γ's from (npγ) reactions. On the other hand, no such spike is seen in the n–signal region R1.

Counting rates in region R1 between days 10 and 33 after the start of the experiment (t=0) are shown in Fig. 4b. The counting rate is almost an order of magnitude lower than in Fig. 4a. From day 16, only cell 1 (with the single rod) continued to be monitored up to day 30. During this period the observed signal plus background rate was 0.1472 ± 0.0004 s^{-1}. The background was determined with a dummy cell, identical (with D_2O/LiOD) except for the presence of a Pd rod, between days 30 and 33 with a measured rate of 0.1472 ± 0.0008 s^{-1}.

This implies a maximum signal rate of 0.0 ± 0.0012 s^{-1}, which, together with the measured efficiency of 0.015, results in an upper limit of 0.08 n/s for this particular sample. If a D/Pd ratio of one is assumed, then this neutron flux limit corresponds to a (neutron) fusion rate per deuterium pair of $< 2.2\times10^{-24}$ (ddn) fusions/dd−pair.sec. In expressing this ratio in terms of a fusion rate per dd−pair, it is implied that the effect (real to the extent of the upper limit) is a volume effect.

In this paper we have reported on the search for neutrons from any possible deuterium−deuterium fusion reactions inside electrochemically deuterated palladium rods. Using a NaI(Tl) scintillation detector we have measured < 0.08 neutrons/sec for a 0.4x7 cm cast, cold rolled, and annealed Pd rod. This corresponds to < 0.007 n/sec/g Pd, compared to PFH's claimed[1] 2.6×10^{3} n/sec/g Pd. Our upper limit corresponds to $< 2.2\times10^{-24}$ (ddn) fusions/dd−pair.sec, which is approximately 5x lower than that claimed by Jones.[2]

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Figure Captions

Fig. 1 NaI(Tl) scintillator detector system for measuring electrochemically induced dd –> n fusion reactions.

Fig. 2 (a) Pulse height spectrum of a Am–Be calibration source in place of the electrochemical cell measured with a NaI(Tl) detector; (b) typical pulse height spectrum (signal + background) measured during electrochemical deuteration of Pd rods.

Fig. 3 Spectrum used in the ^{3}He analysis of the deuterium content of a loaded Pd rod. The spectrum indicates Rutherford back scattering from the Pd and proton and alpha particle signals from ^{3}He–d interactions. The energy associated with the outgoing proton (1.17 MeV) is determined by the energy loss in the solid state detector with a depletion layer smaller than the proton range in silicon.

Fig. 4 (a) Counting rate in the 2.2 MeV region showing the vulnerability of this spectral region to natural radioactivity background. The spike occurred by temporarily disturbing the shielding during days 16 and 17 after the start of the electrolysis process; (b) counting rate in the 3.5–7 MeV region during the electrochemical deuterium loading of 3 Pd rods. Data between days 17 and 33 are from a single cell with a 0.4 cm diameter Pd rod. Background data (with identical cell, but without the Pd rod) are shown between days -30 and 33.

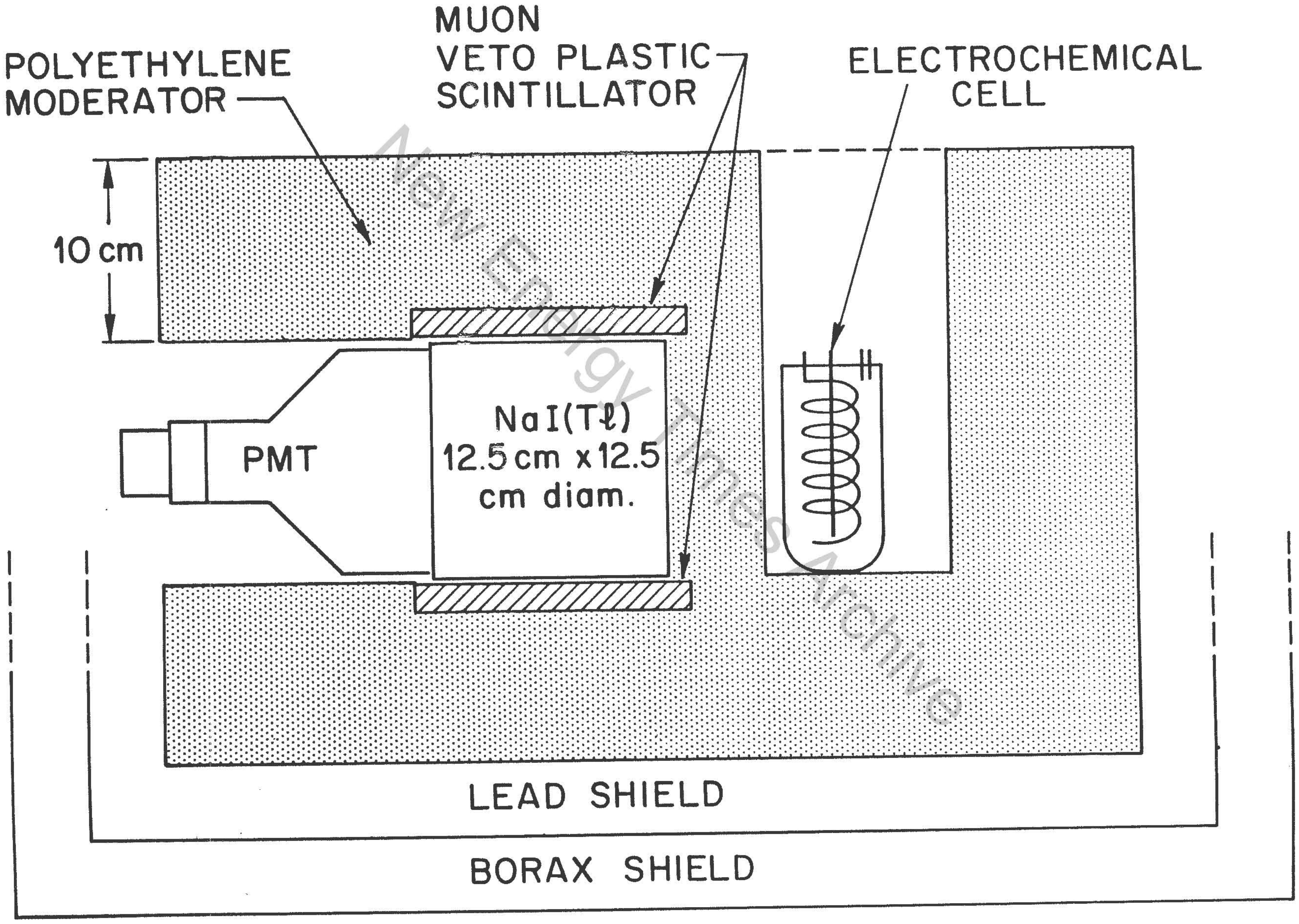
POLYETHYLENE MODERATOR
MUON VETO PLASTIC SCINTILLATOR
ELECTROCHEMICAL CELL
10 cm
PMT
NaI(Tℓ) 12.5 cm x 12.5 cm diam.
LEAD SHIELD
BORAX SHIELD

Fig. 1

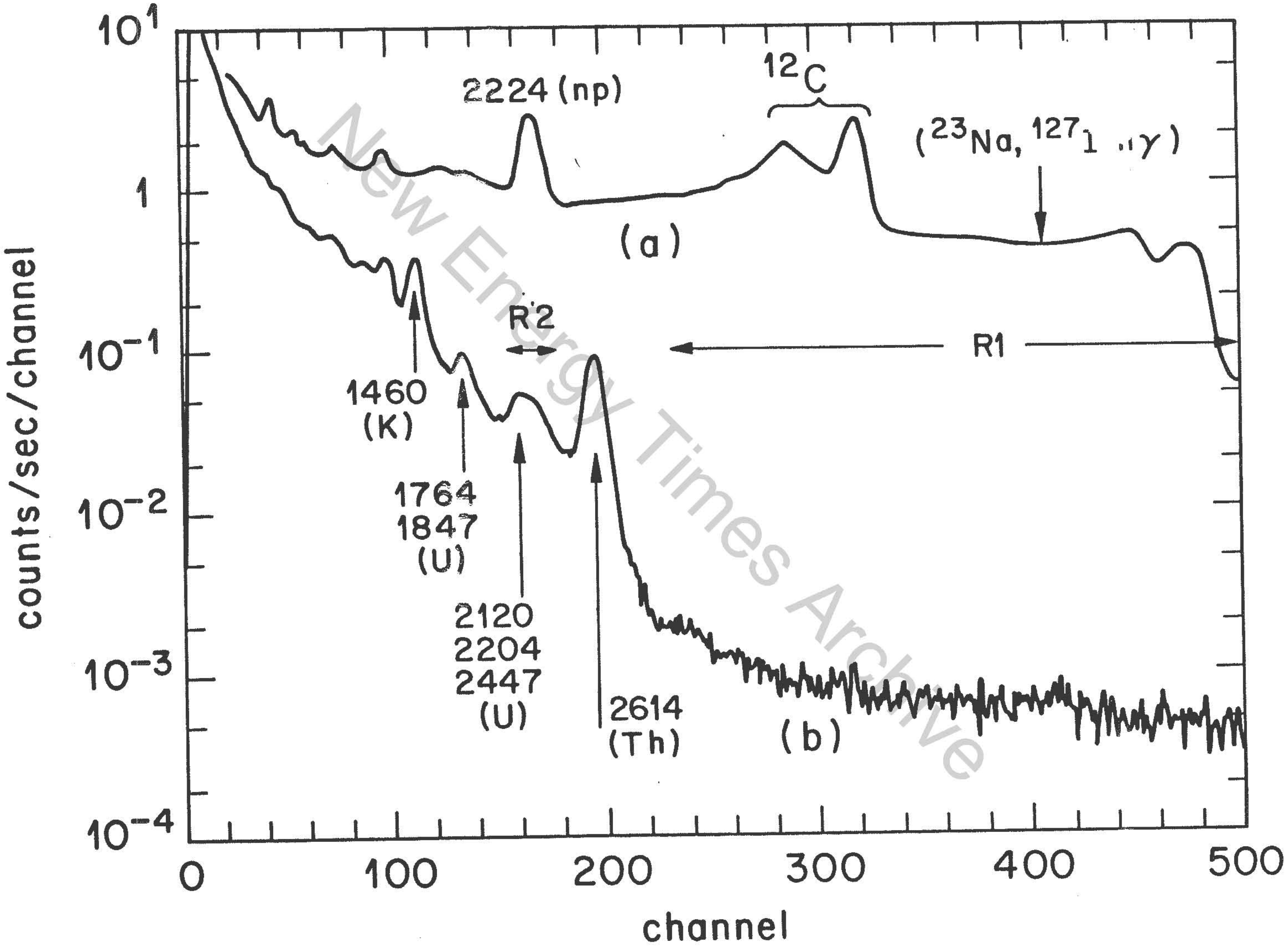
10^1
1
10^-1
10^-2
10^-3
10^-4
counts/sec/channel
0
100
200
300
400
500
channel
2224 (np)
12C
(23Na, 127I n,γ)
(a)
(b)
R1
R2
1460 (K)
1764 1847 (U)
2120 2204 2447 (U)
2614 (Th)

Fig. 2

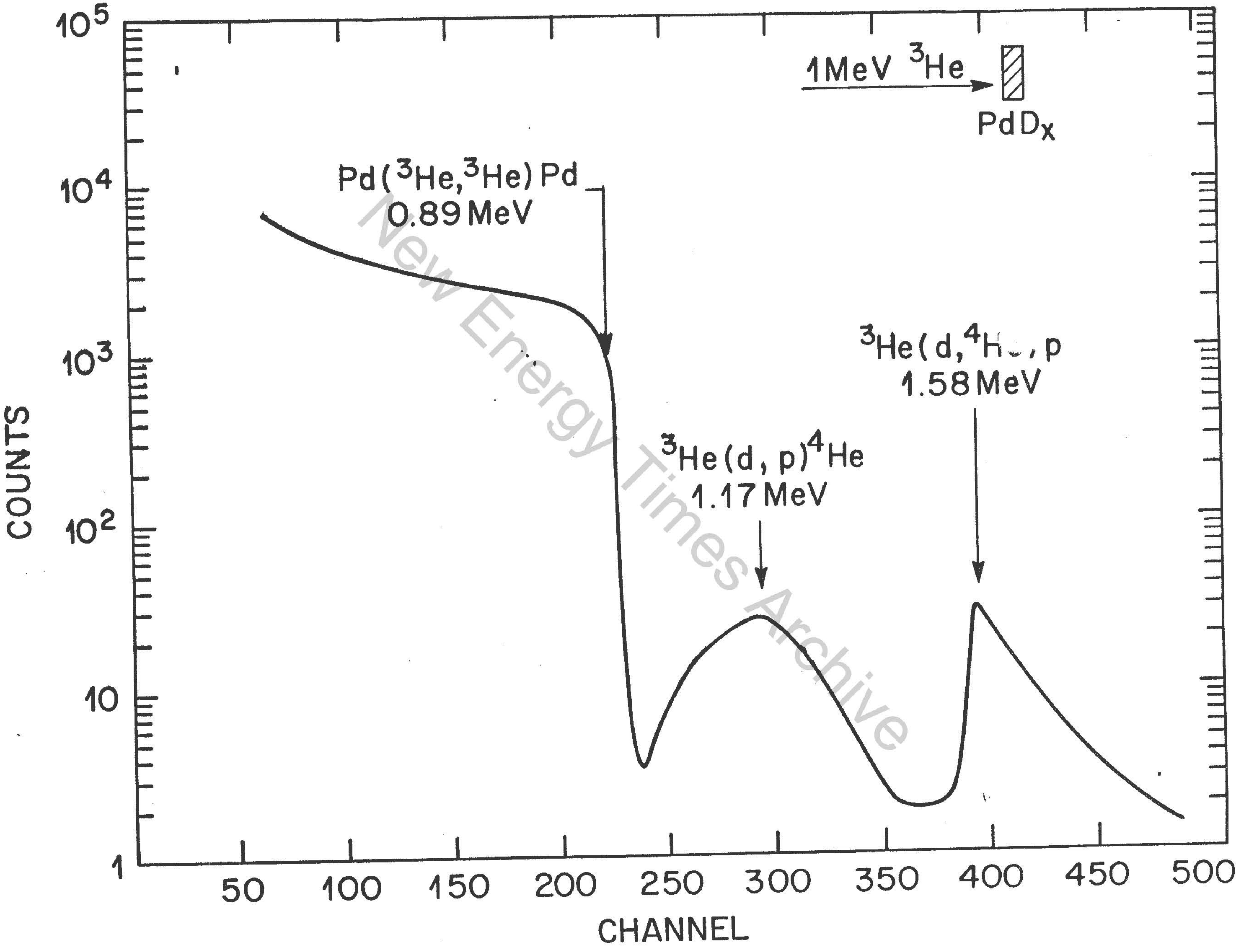
COUNTS
10^5
10^4
10^3
10^2
10
1
50
100
150
200
250
300
350
400
450
500
CHANNEL
1MeV ^{3}He
PdD$_x$
Pd(^{3}He,^{3}He)Pd
0.89 MeV
^{3}He(d, p)^{4}He
1.17 MeV
^{3}He(d,^{4}He)p
1.58 MeV

Fig. 3

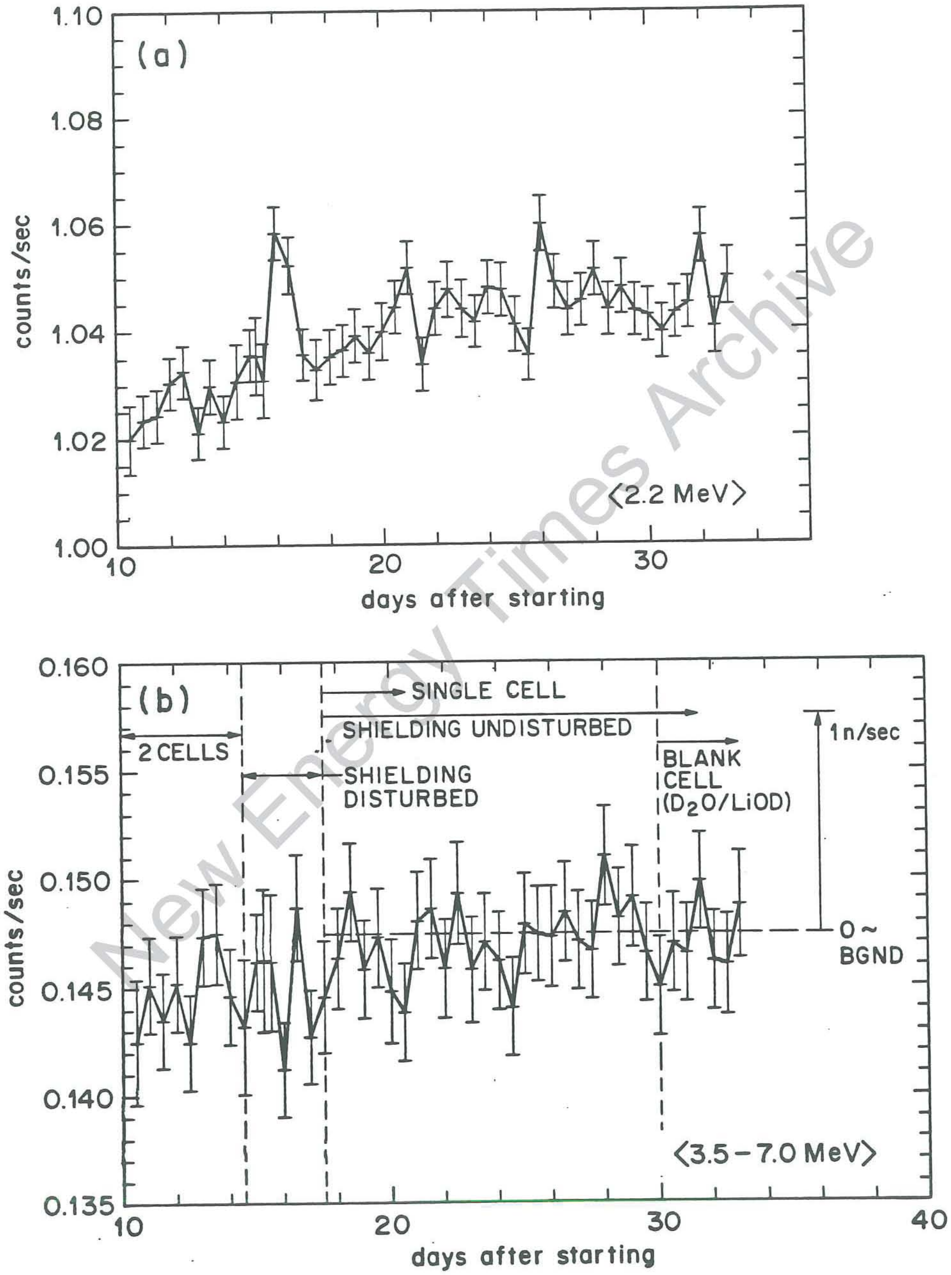
(a)
counts/sec
1.10
1.08
1.06
1.04
1.02
1.00
10
20
30
days after starting
<2.2 MeV>
(b)
counts/sec
0.160
0.155
0.150
0.145
0.140
0.135
10
20
30
40
days after starting
2 CELLS
SHIELDING DISTURBED
SINGLE CELL
SHIELDING UNDISTURBED
BLANK CELL (D_2O/LiOD)
1 n/sec
0 ~ BGND
<3.5 – 7.0 MeV>

Fig. 4

8

U. S. NAVAL RESEARCH LABORATORY
4555 OVERLOOK AVENUE S.W., WASHINGTON, D.C. 20375

Dr. James Eridon
Code 4672
202-767-4800

August 17, 1989

Dr. William Woodard
U.S. Dept. of Energy
ER-6 3F-061
Office of Energy Research
1000 Independence Avenue, SW
Washington, D.C. 20077-9381

Dear Dr. Woodard:

This letter is in response to the request of John Huizenga for reports on the measurement of tritium in cold-fusion electrolytic cells. Our research in the Condensed Matter and Radiation Sciences Division here at NRL is proceeding along non-electrolytic lines. We are irradiating palladium foils with low-energy deuterium ions in order to achieve high D/Pd ratios and then looking for the reaction products using solid state nuclear detectors. If the reaction is nuclear in character and produces tritium, we would likely see this with our particle detectors. We have not yet found any convincing evidence of tritium, or any other massive particle reaction products. We have some interesting results, but nothing to confirm the cold-fusion reaction.

Sincerely;

James Erid

James Eridon

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PURDUE UNIVERSITY

DEPARTMENT OF PHYSICS

August 10, 1989

Dr. John R. Huizenga
Co-Chairman, Cold Fusion Panel
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, D.C. 20585

Dear Dr. Huizenga:

As you requested in your letter of July 20, 1989, I am sending you a short summary of my past and present research on nuclear fusion.

Enclosed are one copy each of (1) "Short Summary", (2) a preprint (reference 5) entitled "New Cold Nuclear Fusion Theory and Experimental Tests", and (3) a preprint (reference 6) entitled "Neutron-Induced Photonuclear Chain-Reaction Process in Palladium Deuteride".

In my summary, two aspects of my fusion research are emphasized: (a) neutron-induced chain-reaction processes as a possible explanation of the effect reported by Fleischmann et al. and others, and (b) importance of and urgent need for designing and building new neutron-induced fission-fusion reactors for large-scale power generation, utilizing existing and/or new fission and fusion reactor technologies, **regardless** of whether the final outcome and results of "cold fusion" reported by Fleischmann et al. and others turn out to be valid or not.

Sincerely,

Yeong E. Kim

Yeong E. Kim
Professor of Physics
Phone: (317)494-3042
FAX: (317)494-0706

Enclosures

cc:

Mr. John H. Schoettler, Chairman, DOE Energy Research Advisory Board
Admiral James D. Watkins, Secretary of DOE
Dr. D. Allan Bromley, White House Science Advisor

Short Summary of Research*
on
Neutron-Induced Chain-Reaction Processes for Large-Scale Power Generation and for Electrolysis with Palladium Deuteride

Y.E. Kim

Department of Physics
Purdue University
West Lafayette, Indiana 47907

August, 1989

*Submitted to Dr. John R. Huizenga, Co-Chairman, Cold Fusion Panel to the DOE Energy Research Advisory Committee.

Neutron-induced chain-reaction processes for large-scale power generation and for electrolysis with palladium deuteride

Y.E. Kim
Department of Physics, Purdue University, West Lafayette, Indiana 47907, USA

Tritium production and excess heat generation above that due to the electrode reaction observed by Fleischman, Pons, and Hawkins (FPH)[1] and others[2,3,4] in their electrolysis experiments with a palladium cathode immersed in heavy water (with 0.1M LiOD) can not be explained by known single-step nuclear reactions such as deuterium-deuterium fusion, since the reaction cross-sections and rates are too small at room temperature. However, a combination of known nuclear reactions can form a set of closed chain reactions which can become self-sustaining at a critical stage under favorable conditions and geometries, as in the well-known case of neutron-induced fission chain reactions. The FPH effect is described in terms of chain-reaction processes involving (a) neutron-induced fission-fusion chain reactions[5] and (b) neutron-induced photonuclear chain reactions in palladium deuteride.[6]

The process (a) involves neutron-induced fission of lithium with the resultant tritium (2.73 MeV) participating in tritium-deuterium fusion. The process (b) involves radiative neutron capture by ^{108}Pd with the resultant γ-rays ($\lesssim$ 6.15 MeV) breaking up deuterium by photodisintegration. Each hypothesis for the FPH effect leads a set of predictions which can be tested experimentally. Experimental evidence and suggested tests for each hypothesis are given.[5,6]

The chain-reaction process (a) can be used **without** the use of electrolysis to design new fission-fusion reactors for large-scale power generation, when an external (continuous or pulsed) neutron flux is included.[5] The process involves self-sustaining chain reactions: (1) $n + {}^6Li \rightarrow {}^4He + T$ and/or $n + {}^7Li \rightarrow {}^4He + T + n$, and (2) T + D $\rightarrow {}^4He + n$, in $Li - D$ plasma or pellet surrounded by Li and other blankets and by neutron reflectors. The use of an external neutron flux as the initial ignitor of the chain reactions, (1) → (2), has an important practical consequence in that the fusion ignition is accomplished by nuclear energy generated from reactions, (1), instead of by an enormous electromagnetic energy input as required for the conventional fusion reactor designs. The feasibility of achieving a controlled self-sustaining state for the chain reactions, (1) → (2), in Li-D plasma or pellet will depend on the geometries and the materials for blankets and reflectors used in the design of fission-fusion reactors, and will also depend on currently available and/or new fission and fusion reactor technologies.

Prototype fusion reactors, based on the conventional designs for both plasma and inertial confinement fusions, have not yet achieved a break-even stage for a sufficient time duration in spite of enormous scientific and engineering efforts invested during the last two decades. Therefore it is important and urgent to investigate the feasibility of achieving a controlled self-sustaining stage in new prototype fission-fusion reactors based on the above chain-reaction process (a) with the use of an external neutron flux.

Theoretical reaction-rate estimates for specific reactor designs based on the reaction chain, (1) → (2), and also on other neutron-induced reaction chains are being investigated using Monte Carlo simulations.

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1. Fleischmann, M., Pons, S., and Hawkins, M., Journal of Electroanalytic Chemistry, **261**, 301 (1989); and errata, **263**, 187 (1989).

2. Appleby, A.J., Srinivasan, S., Kim, Y.J., Murphy, O.J., and Martin, C.R., "Evidence for excess heat generation rates during electrolysis of D_2O in LiOD using a palladium cathode – a microcalorimetric study", a talk presented by Appleby at Workshop on Cold Fusion Phenomena, May 23-25, 1989, Santa Fe, New Mexico; "Anomalous calorimetric results during long-term evolution of deuterium on palladium from lithium deuteroxide electrolyte" to be published in Nature; Appleby, A.J., Kim, Y.J., Murphy, O.J., and Srinavasan, S., "Specific effect of lithium ion on anomalous calorimetric results during long-term evolution of deuterium on palladium electrodes", submitted to Nature.

3. Wolf, K.L., Packham, N.J.C., Lawson, D.R., Shoemaker, J., Cheng, F., and Wass, J.C., "Neutron emission and the tritium content associated with deuterium loaded palladium and titanium metals", in the Proceedings of Workshop on Cold Fusion Phenomena, May 23-25, 1989, Santa Fe, New Mexico, to be published in J. Fusion Energy.

4. Huggins, R.A. in the Proceedings of Workshop on Cold Fusion Phenomena, May 23-25, 1989, Santa Fe, New Mexico, to be published in J. Fusion Energy.

5. Kim, Y.E., "New cold nuclear fusion theory and experimental tests", in the Proceedings of Workshop on Cold Fusion Phenomena, May 23-25, 1989, Santa Fe, New Mexico, to be published in J. Fusion Energy.

6. Kim, Y.E., "Neutron-induced photonuclear chain-reaction process in palladium deuteride", Purdue Nuclear Theory Group Report PNTG-89-7 (July, 1989).

PNTG-89-6
June 1989

New Cold Nuclear Fusion Theory and Experimental Tests*

Y.E. Kim

Purdue Nuclear Theory Group
Department of Physics
Purdue University
West Lafayette, IN 47907, U.S.A.

Abstract

A theory of neutron-induced tritium-deuterium fusion at room temperature is developed, based entirely on previously measured cross-sections of known nuclear reactions. The fusion process involves self-sustaining chain reactions: (1) $n + {}^6Li \rightarrow {}^4He + T$ and/or $n + {}^7Li \rightarrow {}^4He + T + n$, and (2) $T + D \rightarrow {}^4He + n$, in $Li - D$ plasma or pellet surrounded by Li and other blankets and by neutron reflectors.+ The recent results of cold deuterium fusion reported by Fleischmann, Pons, and Hawkins are described in terms of this fusion process. Experimental evidence and tests of the chain reaction hypothesis are described.

*An extended summary of a talk presented at the Workshop on Cold Fusion Phenomena, Santa Fe, New Mexico, May 23-25, 1989; to be published in the workshop proceedings.

+Patent applications pending.

PNTG-89-7
July 1989

Neutron-Induced Photonuclear Chain-Reaction Process in Palladium Deuteride

Yeong E. Kim
Department of Physics
Purdue University
West Lafayette, IN 47907

ABSTRACT

Recently, it has been reported by Fleischmann, Pons, and Hawkins (FPH) that tritium production and excess heat generation above that due to the electrode reaction have been observed in their electrolysis experiments with a palladium cathode immersed in heavy water with 0.1M LiOD. The FPH effect cannot be explained by known single-step nuclear reactions such as deuterium-deuterium fusion, since the reaction cross-sections and rates are too small at room temperature. However, a combination of known nuclear reactions can form a set of closed chain reactions which can become self-sustaining at a critical stage under favorable conditions and geometries, as in the well-known case of neutron-induced fission chain reactions. In this paper, the FPH effect is described in terms of a chain-reaction process involving neutron-induced photonuclear chain reactions in palladium deuteride. Experimental evidence and tests of this chain-reaction hypothesis for the FPH are described.

9700 South Cass Avenue, Argonne, Illinois 60439

Telephone: (312) 972-3513

August 22, 1989

Dr. John R. Huizenga
Co-Chairman
Cold Fusion Panel
Energy Research Advisory Board
United States Department of Energy
100 Independence Avenue, S.W.
Washington, D.C. 20585

Dear Dr. Huizenga:

Thank you for your letter of July 13, 1989 and the Draft Interim Report of the Cold Fusion Panel to the Energy Research Advisory Board. In your letter, you requested that a summary of Argonne's past and present research on cold fusion be sent to you by September 15, 1989 so that Argonne's work in this field can be factored into your final report.

An Interim Report of "Cold" Fusion Experiments at Argonne National Laboratory covering the period March 24 - May 12, 1989 was made available to you in the middle of May. Since then, work has continued in several areas which will be briefly discussed below. I attach several updated, somewhat more extensive summaries of that work and in particular, a preprint of a paper by Redey et al. on calorimetric measurements.

Excess Heat

The paper entitled, "Calorimetric Measurements on Electrochemical Cells with Pd-D Cathodes" by L. Redey, K. Myles, D. Dees, M. Krumpelt and D. R. Vissers describes two series of experiments performed to determine the conditions of cell operation that produce sufficient excess heat to be useful for the production of energy. In the first series, the results from a differential temperature analysis of identical light- and heavy-water electrochemical cells were ambiguous and, thus, not suitable for evaluating excess heat effects. In the second series, two Pd-D/LiOD-saturated D_2O/Pt cells were operated at current densities between 15 and 500 mA/cm^2 in a constant-heat-loss-rate twin calorimeter for 460 hours. Water loss measurements during the experiments indicated that the recombination reaction ($D_2 + O_2 \rightarrow D_2O$) did not occur. The D/Pd ratio was determined gravimetrically during the experiments. No excess heat was found within the sensitivity (0.13 W, 0.082 W/cm^3 of Pd, 0.013 W/cm^2 of Pd) and precision (±0.3 W) of the calorimeter.

Fusion Products

M. Tetenbaum, G. Felcher, M. Blander and J. Carpenter built two detectors for cold fusion experiments, both of the "long counter" type. One has a single high pressure ^{3}He proportional counter and a small polyethylene moderator for use as a background monitor, the other has eight high pressure ^{3}He proportional counters surrounding a central well for electrolytic cells in a 30x30x30 cm^3 polyethylene moderator; this is surrounded by 2.5 cm-thick B_4C shielding. The efficiency of the well detector, for fission neutrons from a 4900 n/sec ^{248}Cm spontaneous fission calibration source in the central well, is about 20%, and the background is approximately 22 counts per minute, consistent with rough estimates of the rate due to cosmic ray generated neutrons in the laboratory.

For all but two of the runs, the neutron counts were consistent with the background. For two successive runs the apparent number of counts rose significantly above the background. This was apparently due to the effect of a water mist emanating from the electrolyte and generated mechanically by bubbles of D_2 and O_2 released from the cell. The mist shorted the detectors in a manner that increased the apparent neutron count. The apparatus was modified to doubly isolate the detectors from the cell.

The results obtained with the modified apparatus give a source rate S_{max} = 0.018 neutrons/sec which is to be compared with the result of Jones et al. who report observing an act of 0.06 neutrons/sec.

K. Rehm, W. Kutschera and G. Perlow searched for the production of protons from the D(d,p)T reaction using an electrolytic cell connected to a proportional counter (PC). The cathode was a thin (31 mg/cm^2) Pd foil (area = 0.6 cm^2) separating the gas (a 90%-argon 10%-methane mixture) in the counter from the electrolyte (0.1 M LiOD in D_2O). The response of this detector setup to protons generated at various depth within the Pd foil was simulated in a Monte Carlo calculation and an efficiency of the PC for proton detection of 28% was calculated. The current densities in the cell ranged from 10-650 mA/cm^2. The setup has been in operation for about 8 weeks. Several runs with the current switched on and off, with different Pd foils, and with electrolytes of LiOD in D_2O and LiOH in H_2O have been performed with the longest individual run lasting more than 10 days. No difference in the counting rate was observed that could be attributed to the electrolytic cell being on or off. Since in addition to the energy measured in the PC the time for each event was recorded, the time structure of the count rate could also be analyzed.

Including the efficiency of the detector system an upper limit for the cold fusion rate of less than (2.1×10^{-3}) (2σ-error) has been obtained. With the assumption of a ratio between Pd and D of 1:1 an upper limit of 4×10^{-23} fusion-events/dd-pair/sec (2σ-error) has been deduced.

S. Zaromb, S. Freedman, D. Krakauer and J. Greene searched for the emission of charged nucleons (H^+, D^+, T^+, $^3He^{++}$ or $^4He^{++}$) to account for the excess energy generation claimed by Fleischmann and Pons. In particular, the reaction $^6Li + D \rightarrow 2\ ^4He$, although extremely unlikely in vacuo due to a high Coulomb barrier, might conceivably be catalyzed in palladium by certain favorable instantaneous configurations of electron clouds. Such a reaction could generate alpha particles having sufficient energy (ca. 8 MeV) to pass through a 0.002-cm thickness of palladium. They constructed an electrolytic cell in which a 2.5-cm diameter smooth Pt anode is parallel to and spaced by a 1.0-cm or 2.5-cm electrolyte gap from a similar 0.0025-cm thick Pd cathode whose back side can be exposed to a charged particle detector. The backside of the Pd cathode had a layer of ^6Li, 80 micrograms/cm^2 thick, evaporated in vacuo at 210-230°C within a 10-minute period and thereafter maintained in vacuo at 150-200°C for 5 hours to effect diffusion of the ^6Li into the palladium. The rationale for this treatment was to: a) block the back of the Pd with a Li-rich phase that might prevent or slow down the escape of deuterium from the Pd lattice; and b) introduce enough ^6Li into that lattice to permit the above reaction, if such a reaction can occur in Pd.

To detect the possible emission of alpha particles from the foil, a silicon surface-barrier detector was used. The detector has a sensitive area of about 1 cm diameter and its distance to the palladium foil is some 5 mm. It is operated at 60 V bias voltage.

Although the detector electronics recorded at one time a peculiar particle energy spectrum (with peaks at around 3 MeV and 6 MeV) when a 1 M $LiOD$ solution in D_2O was electrolyzed at a cathode current density $\geqslant 0.6$ A/cm^2, the effect must be attributed to an experimental artifact, as similar spectra were recorded in some of the control runs. It was therefore decided to discontinue the measurements with the surface-barrier detector and to use, instead, an etch-pit counting approach. Experiments with etch-pit counts and high cathode current densities will be initiated at a low level of effort within the coming months.

To date, the Argonne effort in "cold" fusion has not uncovered convincing evidence supporting this phenomenon. If you have further questions, we will be delighted to provide you with additional information. Please do not hesitate to contact me at any time.

Sincerely,

Alan Schriesheim
Laboratory Director

DMG/jmb

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue, Argonne, Illinois 60439

July 28, 1989

TO: D. Gruen CHM

FROM: L. Redey CMT

SUBJECT: Report on "Cold Fusion" Experiments

Two phases of our experiments on the subject are completed. Further experimental work is deferred until new information on the subject warrants continuation.

A paper, which describes our experiments and findings, has been prepared for the Journal of Fusion Energy for the request of R. A. Krakowski (LANL) who is organizing a special issue on the "cold fusion" subject.

Please find attached a copy of the paper entitled "Calorimetric Measurements on Electrochemical Cells with Pd-D Cathodes" by L. Redey, K. M. Myles, D. Dees, M. Krumpelt, and D. R. Vissers.

We are preparing the data sheet on cold fusion experiment materials and conditions for H. K. Birnbaum (director, Materials Research Laboratory, Urbana, IL). The data sheet will be sent to you as soon as completed.

LR:ltr

CALORIMETRIC MEASUREMENTS ON ELECTROCHEMICAL CELLS WITH Pd-D CATHODES

L. Redey, K. M. Myles, D. Dees, M. Krumpelt, and D. R. Vissers

Electrochemical Technology Program
Chemical Technology Division
Argonne National Laboratory

ABSTRACT

Two series of experiments were performed to determine the conditions of cell operation that produce sufficient excess heat to be useful for the production of energy. In the first series, the results from a differential temperature analysis of identical light- and heavy-water electrochemical cells were too ambiguous and, thus, not suitable for evaluating excess heat effects. In the second series, two Pd-D/LiOD-saturated D_2O/Pt cells were operated at current densities between 15 and 500 mA/cm^2 in a constant-heat-loss-rate twin calorimeter for 460 hours. Water loss measurements during the experiments indicated that the recombination reaction ($D_2 + O_2 \rightarrow D_2O$) did not occur. The D/Pd ratio was determined gravimetrically during the experiments. No excess heat was found within the sensitivity (0.13 W, 0.082 W/cm^3 of Pd, 0.013 W/cm^2 of Pd) and precision ($\pm$0.3 W) of the calorimeter.

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CALORIMETRIC MEASUREMENTS ON ELECTROCHEMICAL CELLS WITH Pd-D CATHODES

L. Redey, K. M. Myles, D. Dees, M. Krumpelt, and D. R. Vissers

Electrochemical Technology Program
Chemical Technology Division
Argonne National Laboratory

INTRODUCTION

The purpose of these experiments was (a) to investigate the energetics of the electrochemical formation of Pd-D, (b) to verify the claims of excess heat generation reported by Fleischmann and Pons,(1) and (c) to ascertain whether an electrochemical cell could be operated to produce sufficient excess heat for the production of useful energy. These experiments were not designed to detect any nuclear radiations and, thus, to verify the results of Jones.(2) This article is based on the presentation given at the Workshop on Cold Fusion Phenomena, Santa Fe, NM.(3)

TECHNICAL APPROACH

Two series of experiments were performed: (a) differential temperature analyses of identical light- and heavy-water electrochemical cells and (b) calorimetric measurements of operating heavy-water electrochemical cells.

In the first series of experiments, the temperature difference between identically constructed Pd-H/LiOH-saturated-H_2O/Pt and Pd-D/LiOD-saturated-D_2O/Pt cells was monitored. It was anticipated that the temperature difference would be close to zero until the onset of "cold fusion," when the D_2O cell would become noticeably hotter. However, it proved to be impossible to maintain identical electrochemical conditions in both cells. For example, to maintain the current densities the same in the two cells, the cell operating voltage of the heavy-water cell became higher than the light-water cell; this in turn caused the temperature to be also higher. When the current densities and the cell voltages were both made the same by manipulating the cell resistance, the light-water cell became very slightly warmer (0.8 K). We concluded that the results from this kind of experiment were too ambiguous and, thus, not suitable for evaluating the occurrence of excess heat as has been reported.(4)

In the second series of experiments, Pd-D/LiOD-saturated-D_2O/Pt cells were operated in a constant-heat-loss calorimeter that was sensitive enough to detect the levels of excess heat previously reported.(1,4,5) Excess heat has been generally defined as that heat output from the cell, after suitable corrections have been made to account for several concurrent side reactions, that is greater than the heat equivalent of the electrical energy that was put into the cell. Details of this series of experiments and the associated calculations are described below.

EXPERIMENTAL

The Calorimeter

The schematic of the constant-heat-loss-rate water calorimeter that was built for the specific purpose of this experiment is shown in Fig. 1. The electrochemical cell, located in the water of the calorimeter, was controlled at 30.0°C. The constant-temperature bath that surrounded the calorimeter was held at 21.0°C by flowing the water through a controlled-temperature circulator. A heat-loss-rate control gap regulated the rate of heat transfer between the calorimeter and the bath. The heat loss rate (Q_c) was varied by placing air in the gap for levels of cell heat production up to 5 W and water in the gap for levels up to 30 W. The bath was thermally insulated from the surroundings by thick layers of styrofoam. The cover was insulated to prevent any significant direct heat loss to the ambient air through the top of the cell. The heat loss from the calorimeter was calibrated with a precision electrical heater that was placed into the electrolytic cell. A stirrer kept the water temperature of the calorimeter uniform; however, in this type of calorimeter, neither the temperature of the electrochemical cell nor any nonuniform temperature distribution in the cell affects the precision of the heat measurement. Prior to operation of the electrochemical cell, the calorimeter was calibrated by introducing known resistive heat inputs.

The principle of the calorimeter is illustrated in Fig. 2. To maintain the temperature of the calorimeter constant, the rate of heat loss from the calorimeter to the bath (W_L) was precisely compensated for by adjusting the heat input from the electrical heater (W_H). When the electrochemical cell was off, $W_L = W_H$; when the electrochemical cell was on and produced heat, the heater input was decreased in accord with the following relationship:

$$W_L = W_H + Q_C. \tag{1}$$

The constant temperature bath contained twin calorimeters so that two electrochemical cells could be identically operated; thus, the results would emphasize any unusual occurrences that may occur in one of the cells. The electrical circuit diagram for the electrochemical cells is shown in Fig. 3. The power source was a potentiostat (Princeton Applied Research Model 375) operated in the galvanostatic mode. The cell voltage was measured by high precision digital meters.

The overall precision of the heat flux, determined to be ±0.3 W at low Q_c and ±0.4 W at high Q_c, was limited by some slight temperature oscillations experienced by the calorimeter, which were in the range of 0.1°C. Because these oscillations were quite slow (less than 0.1°C/6 h), the sensitivity of the calorimeter was better--approximately 0.13 W over a period of one hour. The time constant of the calorimeter to reach steady state after changing the current density was about 10 minutes. Included in these values are all the experimental errors related to the measurements of the temperature, cell voltage, heater voltage, and current. When related to the volume, surface area, and weight of the starting Pd cathode, the sensitivity of the calorimeter was 0.082 W/cm^3, 0.013 W/cm^2, and 0.068 W/g respectively. Considering that the reported levels of excess heat(1,4,6) have been around 10 W/cm^3, this precision was more than adequate for the present experimental purposes.

The Electrochemical Cell

Details of the electrochemical cell are shown in Fig. 4. A wrought Pd rod cathode was supplied by Johnson Matthey (AESAR's #12557) and had the following characteristics: 99.96% pure, 0.63 cm diameter, and 5 cm long (1.58 cm^3, 10.29 cm^2, 19 g). The rod was degassed, either at temperatures below 100°C or at high temperatures in vacuum, and then was heat treated before each experiment at 650°C for an hour in air and, finally, at 600°C in vacuum for about 18 hours. A Pt wire anode was supplied by Johnson Matthey (AESAR #10285) and had the following characteristics: 99.95% pure, 0.1 cm diameter, and 100 cm long. The anode wire was wound into a 3.2 cm ID coil to snugly fit into the cell.

The electrolyte was about 40 cm^3 of LiOD-saturated D_2O. The LiOD-saturated D_2O was prepared from 99.9% pure Li metal, supplied by Johnson Matthey (AESAR #10767), and 99.8% pure D_2O, supplied by Aldrich (#15,188-2). Saturated LiOD electrolyte (about 12 w/o) was used to lower the resistivity, compared with that of the 0.1 M LiOD solution used by Fleischmann and Pons(1), produced less irreversible heat during electrolysis and, thus, improved the precision of the experiment. The cell was covered, leaving only a small gap to allow escape of the electrolyzed gases, to minimize the back diffusion of H_2O vapor from the ambient atmosphere. Nevertheless, some H_2O did contaminate the electrolyte as was shown by the post-experiment chemical analysis.

The Pd cathode was supported by a stainless steel tube current lead that was covered by a Nalgene tube to preclude any involvement of the stainless steel in the electrochemical reaction. A thermocouple, inserted through the tube, was in physical contact with the Pd cathode to monitor any rapid temperature excursions that might occur.

Six extended duration experiments were carried out under a wide variety of conditions. The cumulative electrolysis time was 1500 h. The duration and charge input of the longest experiment were 460 h and 700 Ah, respectively. During the course of the experiments, the following measurements were made in addition to the calorimetric ones: (a) the weight of the Pd cathode to calculate the D/Pd ratio, (b) the potential of the PdD_x cathode on closed and open circuit versus a Hg/HgO reference electrode filled with LiOD-saturated D_2O, and (c) the weight of the heavy water added to maintain the electrolyte level in the cell constant to within 0.3 cm.

At the end of the experiment the electrolyte was chemically analyzed. A H/D ratio of 0.02 was found after 460 h of cell operation, presumably the result of some D_2O/H_2O exchange from the atmospheric moisture. An analysis for tritium in the electrolyte (269 d/m/ml) at the end of the same experiment indicated no significant change over that in the as-received heavy-water (138 d/m/ml). The Pd cathode was degassed after the experiment, and the original weight of the palladium still remained. However, the outcoming gas had an average H/D ratio of 0.06 which means that the actual concentration of deuterium in the PdD_x cathode was slightly less than that calculated from only the weight measurements.

DATA EVALUATION

Power Balance

During the operation of the electrolytic cell, several well-identified electrochemical, chemical, and electrical processes occur and produce heat effects in the cell. These processes must be quantified before any assessment of excess heat generation can be made. The processes are those associated with the cell resistance, the electrolysis of heavy water, the absorption of deuterium into the palladium lattice, and the loss of water from the cell. It is assumed in this analysis that no significant amount of recombination had occurred during electrolysis.

The cell impedance includes the ohmic resistance of the cell (R), the polarization of the Pd cathode (η_c), and the polarization of the Pt anode (η_a). The rate of heat generation from these processes is the sum of the individual effects (Q_{IRR}) given by

$$Q_{IRR} = I\ (IR + \eta_c + \eta_a), \tag{2}$$

where I is the cell current. Q_{IRR} is an exothermic process and is often referred to as electrochemical irreversible heat that arises from performing the electrolysis reaction at a finite rate. It can be shown that

$$Q_{IRR} = W_E - I(\Delta G/2F) = I\ (E - 1.2570), \qquad (3)$$

where E is the applied cell voltage, W_E =I E is the electrical power to the cell, ΔG = 242.6 kJ/mol D_2O at 30°C$^{(6,7)}$ is the free energy change in the electrolysis of heavy water, F is the Faraday constant, and 1.257 volts is the thermodynamic voltage.

Even when carried out at a reversible rate, the electrolysis of heavy water (and any other reaction for that matter) produces heat effects equal to the change of entropy (ΔS) multiplied by the absolute temperature (T). For heavy water electrolysis, this heat effect is endothermic, and the rate of heat adsorption (Q_{REV}) at a finite rate is given by

$$Q_{REV} = I\ (T\Delta S/2F) = 0.269\ I, \qquad (4)$$

where ΔS = 170.8 J/K mol D_2O at 30°C$^{(6,7)}$, and 0.269 volts is the value.

The heat generation from the absorption of deuterium becomes negligibly small as the D/Pd ratio in the Pd cathode approaches 0.7.

The water loss processes include the saturation of electrolyzed gases with D_2O vapor and the entrainment of liquid D_2O in the gas leaving the electrochemical cell. An evaluation concluded the sum of all these effects is negligible (less than 1% of the total heat effects) for the present experiments.

Assuming that no excess heat is generated, the net heat output from the electrolysis cell (W_Q) is given by the sum of all the above effects, or

$$W_Q = Q_{IRR} - Q_{REV} = W_E - I\ (\Delta G + T\Delta S)/2F = W_E - I(\Delta H/2F) = I(E - 1.526), \quad (5)$$

where $\Delta H = 294.4$ kJ/mol D_2O at 30°C(6,7) is the enthalpy change in the electrolysis of heavy water and the thermal neutral is 1.526 volts is the value. Intuitively, the enthalpy term in Eq. 5 arises because it is the quantity of power input to the electrolysis cell that produces chemical energy without heat evolution. Therefore, W_Q can be thought of as the adjusted electrical input to the cell.

The excess heat generated can be determined by

$$\text{Excess Heat} = Q_C - W_Q, \quad (6)$$

where Q_C is the measured heat-generation rate of the electrolysis cell transported to the calorimeter, is defined in Eq. 1.

Energy Balance

The energy balance is based on the comparison of the $\int Q_C dt$ and $\int W_Q dt$ integrals calculated for a period of time starting at time t_1 and ending at time t_2. Ideally, the integrals should cover the entire span of the experiment; but, because of the nature of the instrumentation available, it was only possible to calculate the integrals over periods of constant current density of 10- to 50-h durations with acceptable accuracy.

Mass Balance

A mass balance was performed to evaluate how much water was lost from the electrolytic cell due to the saturation of the electrolyzed gases with D_2O

vapor and the entrainment of liquid D_2O in the gas leaving the cell. The mass balance was also used to determine the extent that the electrolyzed gases had recombined in the cell. The mass balance was calculated by determining the rate at which water had to be added to the cell to keep the electrolyte level constant and comparing it to the cell current (knowing that each ampere of current consumes heavy-water at a rate of 6.22 mg/min due to electrolysis and an additional 0.41 mg/min at 30°C due to the saturation of the gases). The loss by entrainment was three orders of magnitude smaller than the loss by electrolysis.

RESULTS AND DISCUSSION

The following chemical processes were addressed in the analysis of the experimental results: the electrolysis of water,

$$2D_2O = 2D_2 + O_2; \tag{7}$$

the recombination of the split D_2 and O_2 gases,

$$2D_2 + O_2 = 2D_2O; \tag{8}$$

The formation of PdD_x from gaseous D_2,

$$xD_2 + 2Pd = 2PdD_x, \tag{9}$$

and from liquid D_2O

$$Pd + xD^+ + xe^- = PdD_x; \text{ and} \tag{10}$$

the decomposition of PdD_x,

$$2PdD_x = 2Pd + xD_2. \tag{11}$$

Whereas the actual reaction steps may be much more complicated than these processes would indicate, the energy calculations only require a knowledge of the beginning and end of the process. Of these processes, the electrolysis of water (Eq. 7) is of primary importance because it dominates the energetics of the experiments.

The electrochemical formation of PdD_x (Eq. 10) made a significant contribution to the power, energy, and mass balances (PEM balances) only during the comparatively short periods in the experiments when the formation of PdD_x was rapid. During most of the experiment, the compositional change of PdD_x was slow, and this reaction then contributed less than 1 percent to the PEM balances, as was deduced from the measured current efficiencies shown in Fig. 5. It should be noted that PdD_x can be formed directly from the gas phase (Eq. 9) at ambient temperatures and pressures only up to about $x = 0.6$; higher concentrations require electrochemical charging.

The decomposition of PdD_x (Eq. 11) occurs when the cell is on open circuit. The rate of decomposition is dependent on the concentration of deuterium in the PdD_x, (Fig. 6) and on the elapsed time after current interruption in accord with Fick's law of diffusion.

The extent that the evolving D_2 and O_2 gases recombine (Eq. 8) must be carefully considered in calculating the PEM balances. The recombination rate is directly related to the rate that the heavy water had to be replenished to keep the level constant in the electrolytic cell. In all of these experiments, the measured replenishment rate was essentially equal (Fig. 7) to the rate that the water was electrolyzed, as calculated with Faraday's law and the measured current input, and increased by the amount of heavy water needed to saturate the evolving gases at 30°C. Because no recombination of deuterium and oxygen was observed, no correction for recombination was included in Eqs. 2-6.

The lack of recombination in our experiments does not exclude the possibility that, under other investigators' experimental conditions, recombination might have occurred and have been overlooked. If recombination does occur, the factor 1.526 in Eq. 5 must be reduced in proportion to the recombination rate. Whereas recombination is slow in liquid D_2O itself because of the low solubility and slow diffusion of D_2 and O_2, there are conditions when fast recombination can occur. For example, on exposed electrolyte-free surfaces of the Pd or Pt electrodes or in the electrolyte when O_2 gas bubbles admix with D_2 gas bubbles on the surface of electrode and recombine. Further, pH changes can occur in the surface layers of the electrodes at high current densities, which can be very pronounced in dilute electrolytes, and create favorable conditions for recombination or peroxide formation. Peroxide, or other impurities, can set up heat-producing irreversible reactions or electrochemical-chemical cycles.

The concentration of deuterium in the Pd cathode was determined by gravemetric measurements. Because some deuterium escaped from the Pd electrode as the measurements were being made, time plots were necessary to extrapolate the weights to when the current to the cell was first interrupted. The decomposition of PdD_x (Eq. 11) produced a very distinct cooling effect while the PdD_x electrode was being weighed. Up to about $x = 0.7$, the deuterium uptake in the PdDx electrode was relatively fast, as is reflected by the observed high current efficiency (Fig. 5). However, very energetic electrochemical conditions were required to achieve higher deuterium concentrations. A manifestation of this is the low electrode potential measured at high concentrations. In the compositional range of the α and $\alpha+\beta$ PdD_x phases, the electrode had potentials in agreement with the literature(8,9), that is, about 30 mV at $x<0.4$ and a gradual decrease to about zero as x reached 0.6 (these potentials are relative to a $Pt(D)/D_2$ electrode prepared with the same electrolyte, and assuming that the Hg/HgO reference electrode used in the measurement had a 920 mV potential against this electrode). At concentrations greater than $x = 0.6$, however, the open-circuit potential of the PdD_x electrode shifted to approximately -90 mV, indicating that the deuterium had a high fugacity and was very energetic in the PdD_x electrode. This negative potential was not stable but did persist for long periods (10-20 minutes) after the current was interrupted and then slowly drifted to less negative values. This behavior was probably due to the decrease in the deuterium in the surface layers of the PdD_x electrode.

The results of the PEM balances are plotted in Figs. 8 and 9. The heat output of the cell (Q_C) and the adjusted electrical input (W_Q) show agreement well within the accuracy limits of the measurements. Thus, no excess heat was found within the limits of the sensitivity and precision of the calorimeter as operated under the described experimental conditions. The experimental conditions encompassed many of the factors that have been suggested as influencing the onset of "cold fusion." These are (a) the Pd cathode had sufficient mass and surface area to meet the reported claims for both bulk effects(1) and surface effects(2); (b) the applied current densities covered the wide range from 12.5 to 500 mA/cm^2 (Fig. 10); (c) the duration of the experiment was long enough to maintain a high concentration of deuterium in the Pd cathode for hundreds of hours (Figs. 10 and 11); and (d) the ratio of

D/Pd in the PdD_x electrode approached 1.0, that is, PdD. The data in Fig. 11 have been corrected for the measured H/D ratios. It should be noted that the deuterium concentration did fluctuate (Fig. 11), even at constant current density for unknown reasons. Because the deuterium concentration in the PdD_x electrode was measured relatively infrequently, the instantaneous rate of change of x is unknown. However, the examination of the continuous temperature record of the PdD_x electrode showed that to within ±0.025°C no sudden temperature changes occurred. Furthermore, our calorimeter could detect a change in x of 0.1 within a 10 minute period assuming an enthalpy of 33 kJ/mol D_2.(8,10,11)

CONCLUSION

No excess heat was observed in Pd/LiOD-saturated D_2O/Pt cells during long duration experiments conducted with a high sensitivity, constant-heat-loss-rate calorimeter. The experimental conditions covered a wide range of parameters that have been described as being important to the production of excess heat. Additionally, quantified were the power/energy/mass balance, deuterium concentration and potential of the palladium cathode, degassing of Pd-D, and tritium level of the electrolyte. All of the observed heat effects were accountable by established electrochemical, chemical, electrical, and thermodynamic processes.

ACKNOWLEDGMENT

The authors are thankful for the support provided by the Office of the Director of the Argonne National Laboratory and for the use of the instrumentation and facilities provided by DOE. The authors also thank

D. G. Graczyk, A. Engelkemeir, and I. M. Fox for the H/D analysis and D. L. Bowers for the tritium analysis. This work is supported by the U.S. Department of Energy under contract W-31-109-Eng-38.

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FIGURE CAPTIONS

Fig. 1 Constant Heat-Loss-Rate Calorimeter

Fig. 2 Mass-, Energy-, and Power Balance Considerations

Fig. 3 Circuit Diagram for Calorimetric Experiments

Fig. 4 Electrolytic Cell for Calorimetric Experiments

Fig. 5 Current Efficiency of PdD_x Formation at Low Current Density ($i<25$ mA/cm^2)

Fig. 6 Degassing Rate of PdD_x at 2 min. after Current Interruption

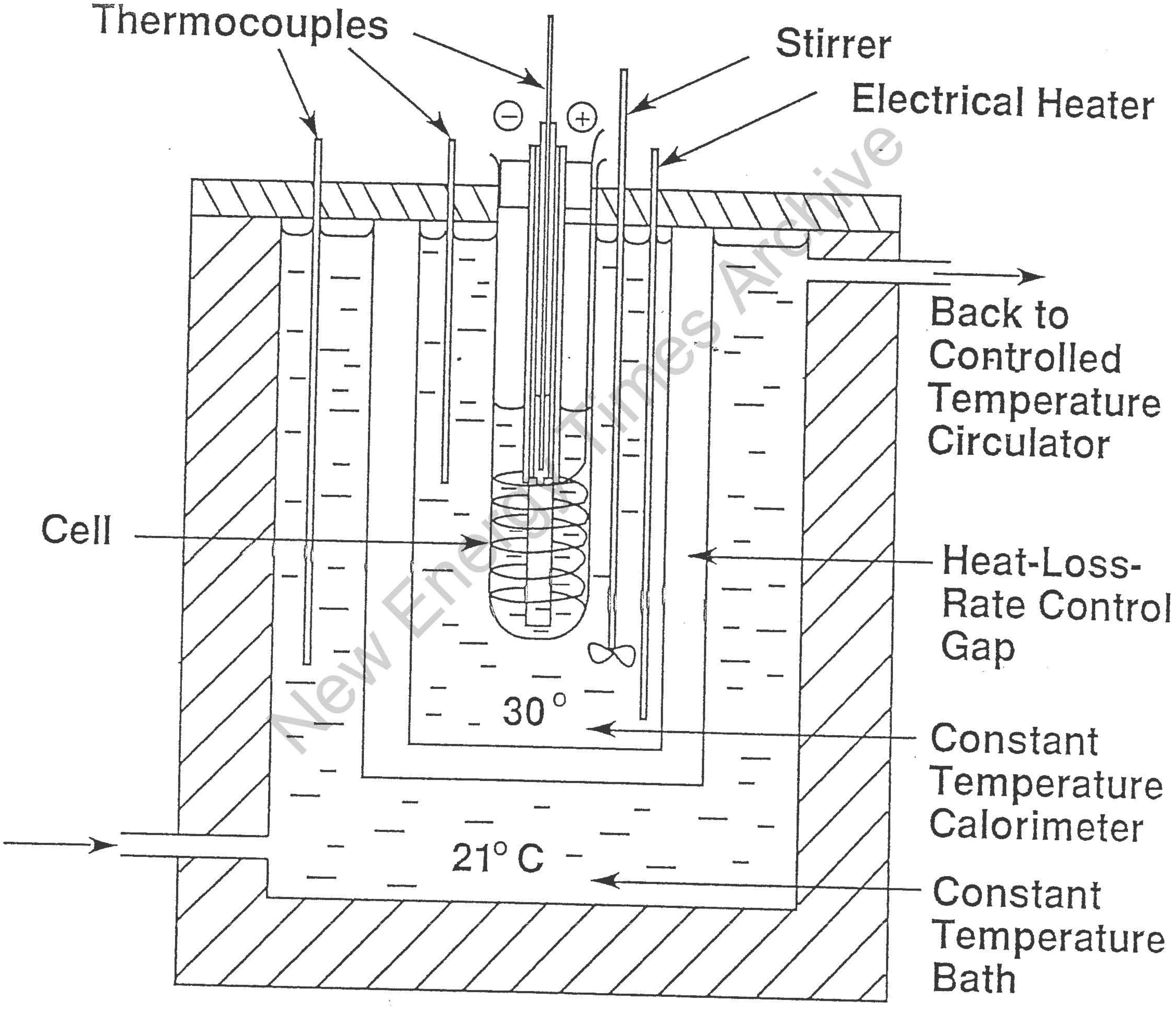
Fig. 7 Water Loss Rate for the Experiment

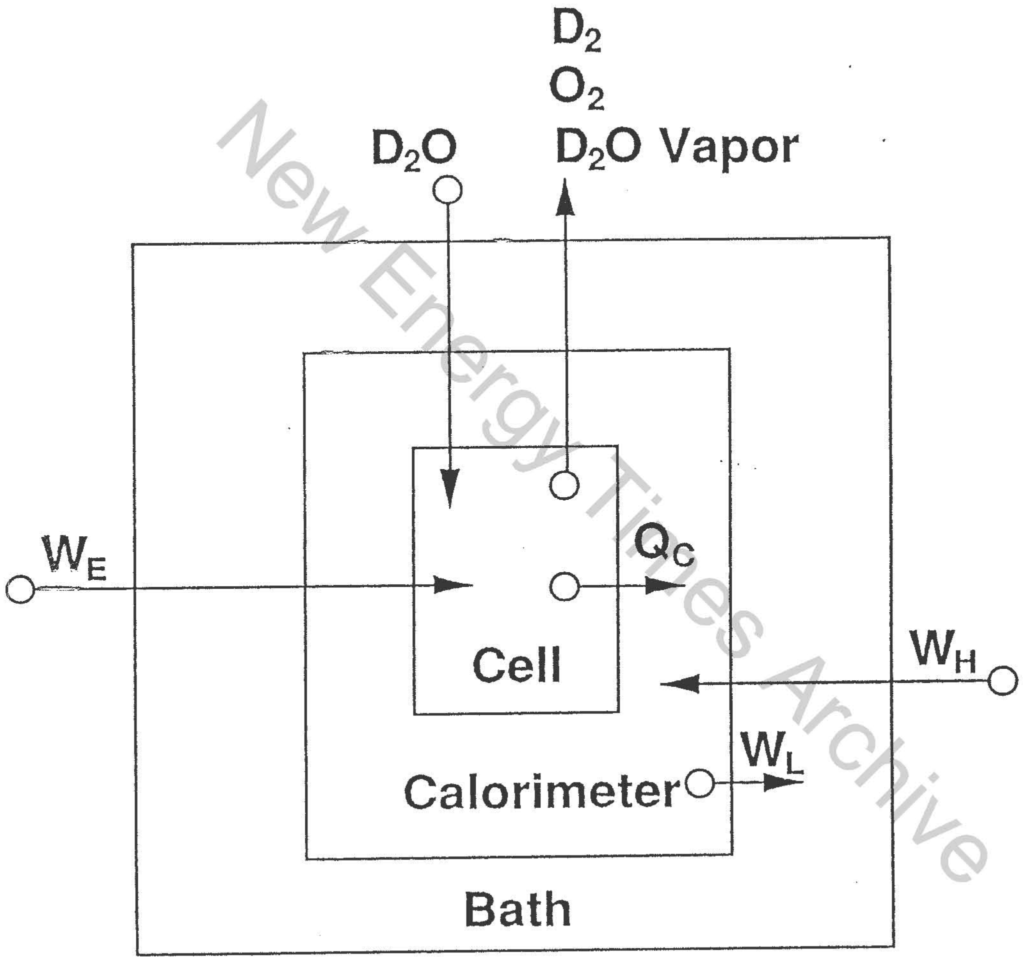
Fig. 8 Comparison of the Heat Output of the Cell (Q_C) and the Adjusted Electrical Input (W_Q)

Fig. 9 Difference of Heat Output (Q_C) and Adjusted Electrical Input (W_Q)

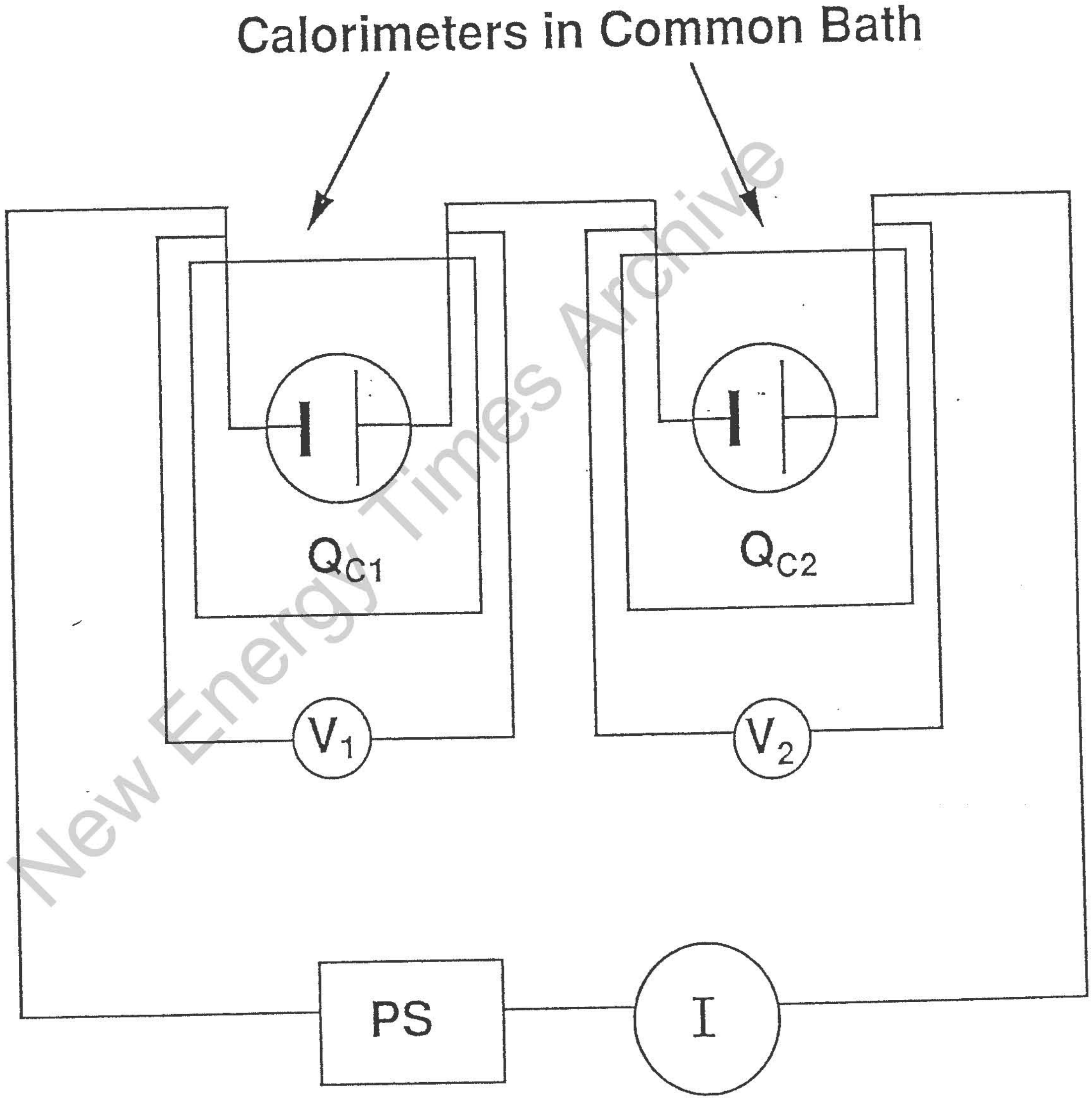
Fig. 10 Current-Density Program for the Experiment

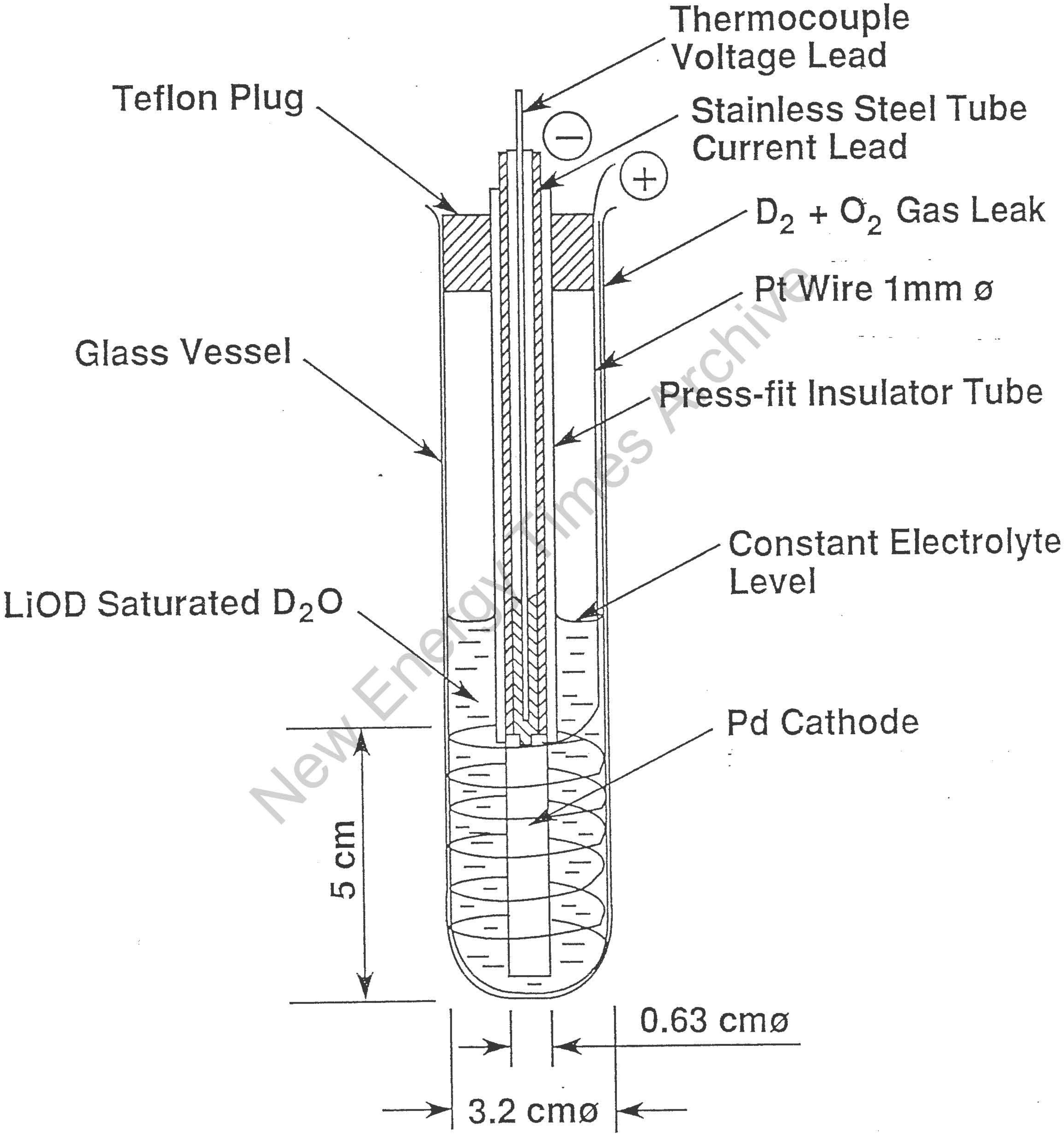
Fig. 11 Deuterium Concentration Variation During the Experiment

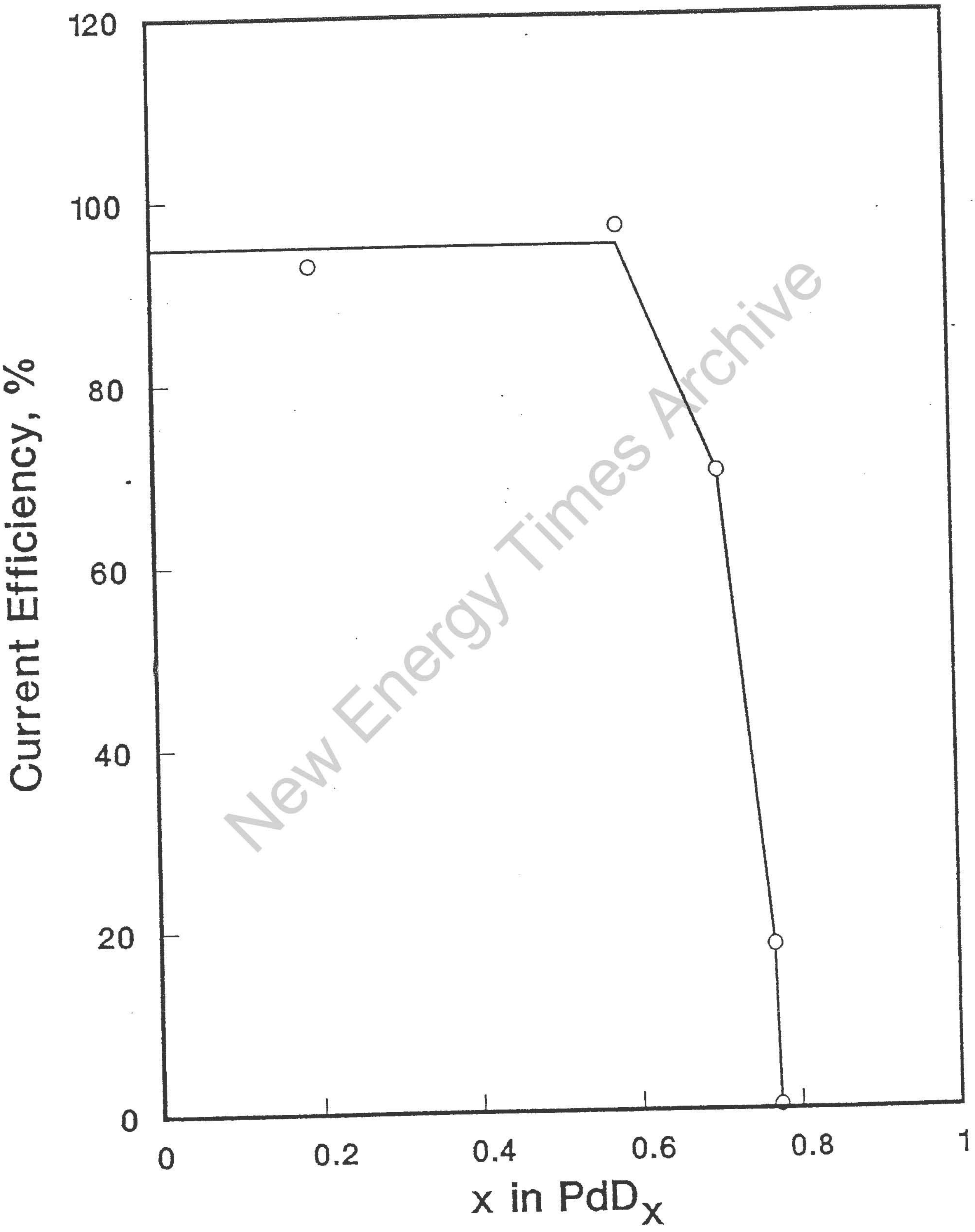

Thermocouples
Stirrer
Electrical Heater
⊖
⊕
Back to Controlled Temperature Circulator
Cell
Heat-Loss-Rate Control Gap
30°
Constant Temperature Calorimeter
21° C
Constant Temperature Bath

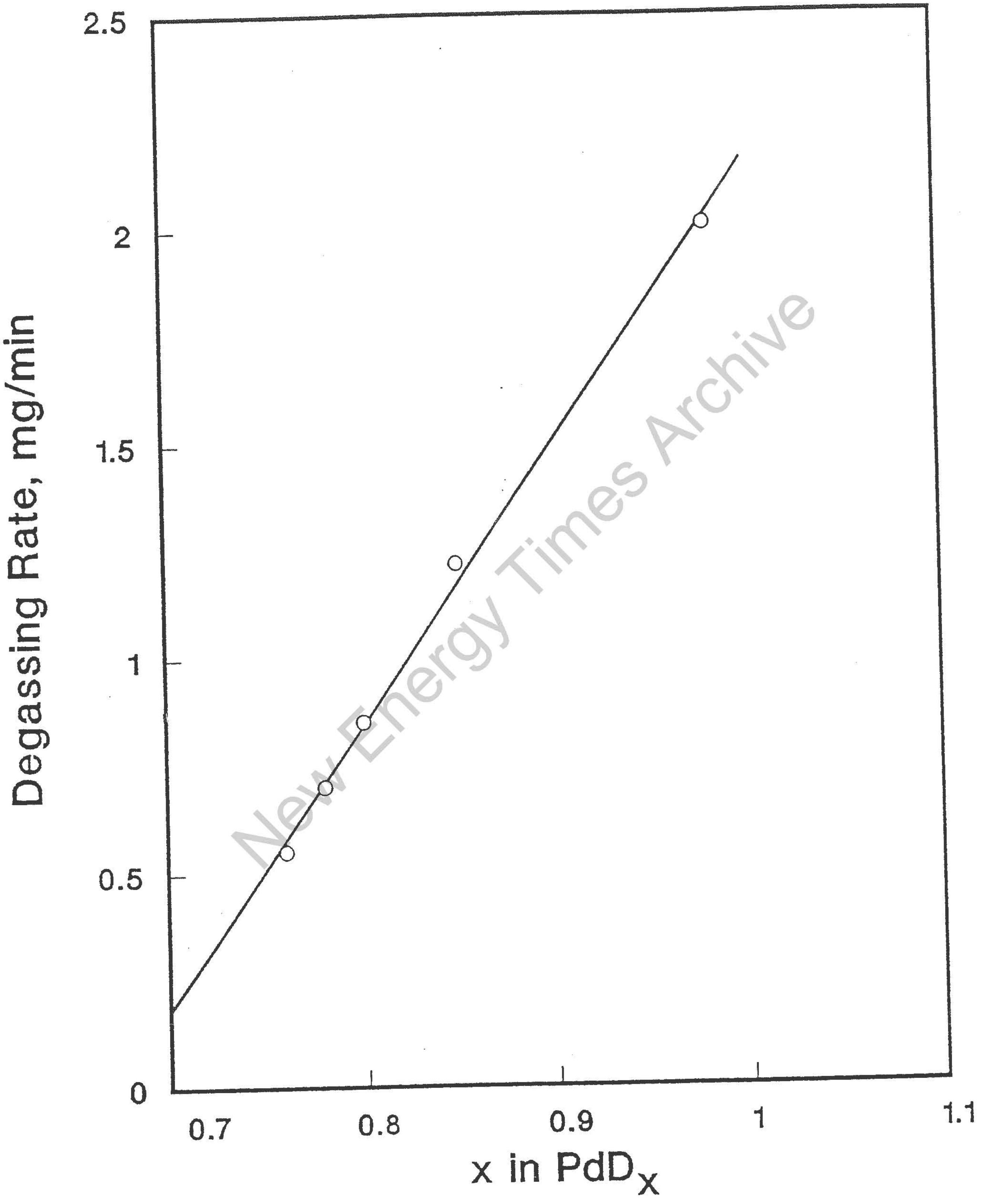


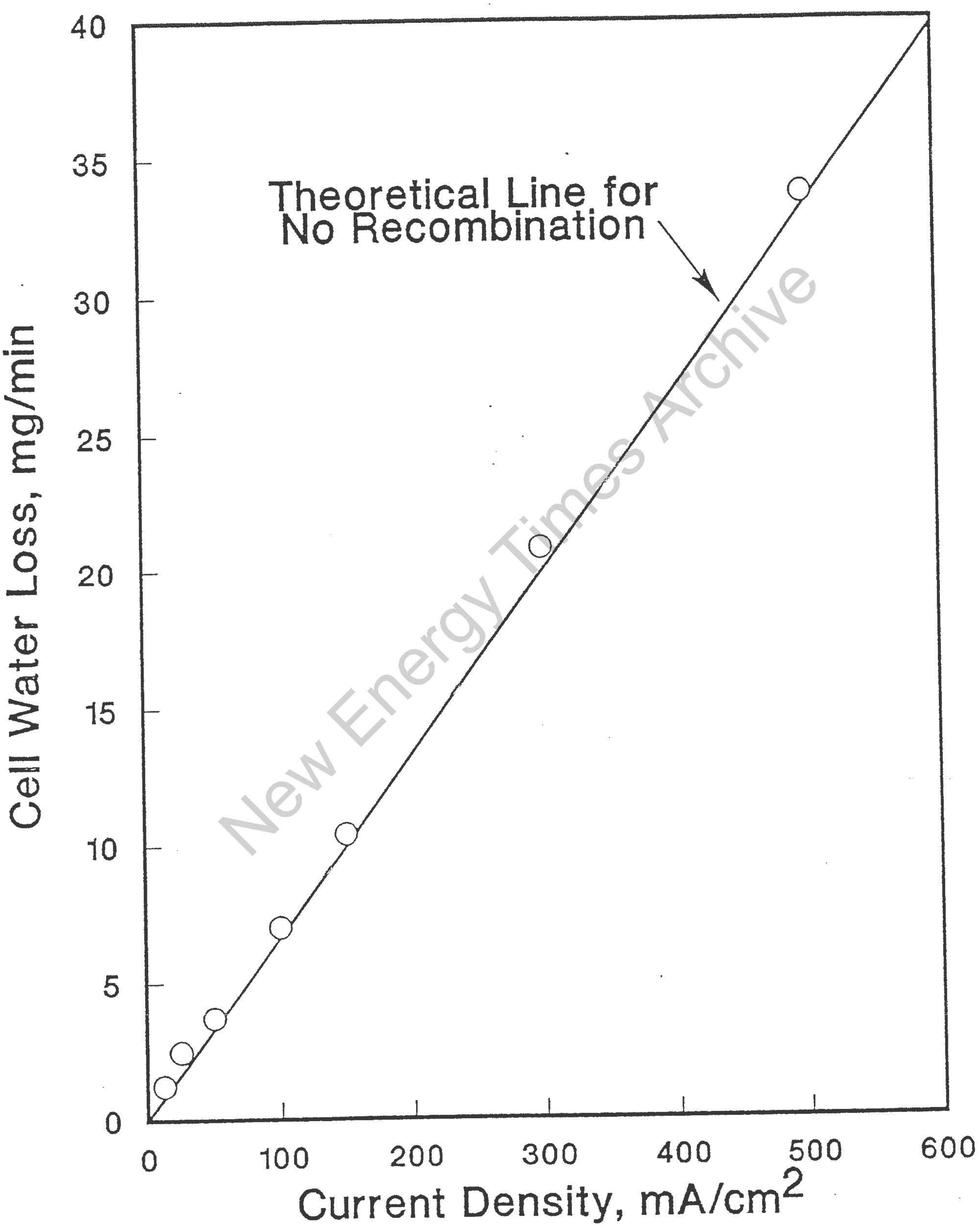
W_L : Heat-loss rate from calorimeter to bath
W_H : Electrical heater power to calorimeter
W_E : Electrical power to cell
Q_C : Heat-generation rate of cell transported to calorimeter


Calorimeters in Common Bath
Q_{C1}
Q_{C2}
V_1
V_2
PS
I

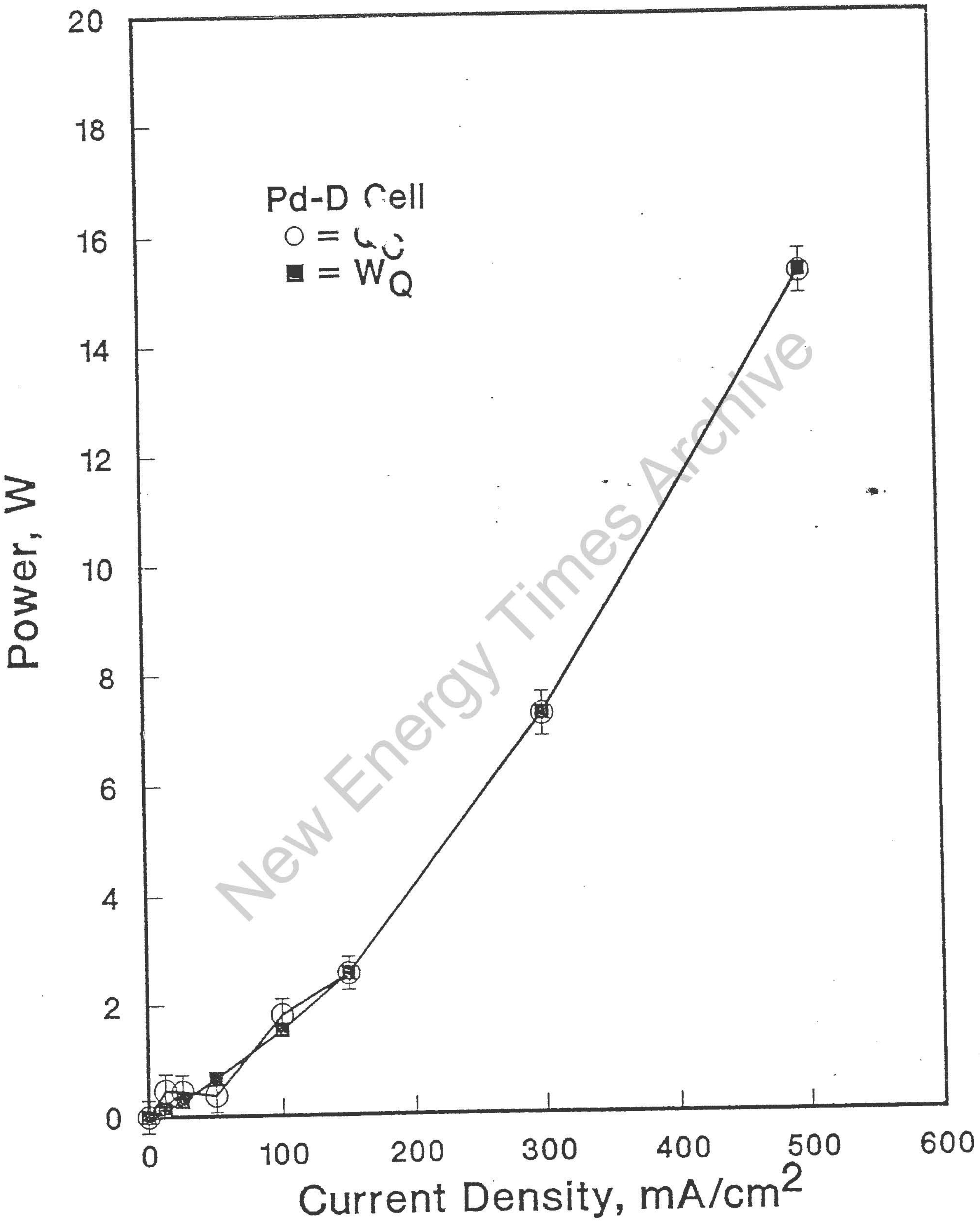

Thermocouple Voltage Lead
Teflon Plug
Stainless Steel Tube Current Lead
−
+
$D_2 + O_2$ Gas Leak
Pt Wire 1mm ø
Glass Vessel
Press-fit Insulator Tube
Constant Electrolyte Level
LiOD Saturated D_2O
Pd Cathode
5 cm
0.63 cmø
3.2 cmø

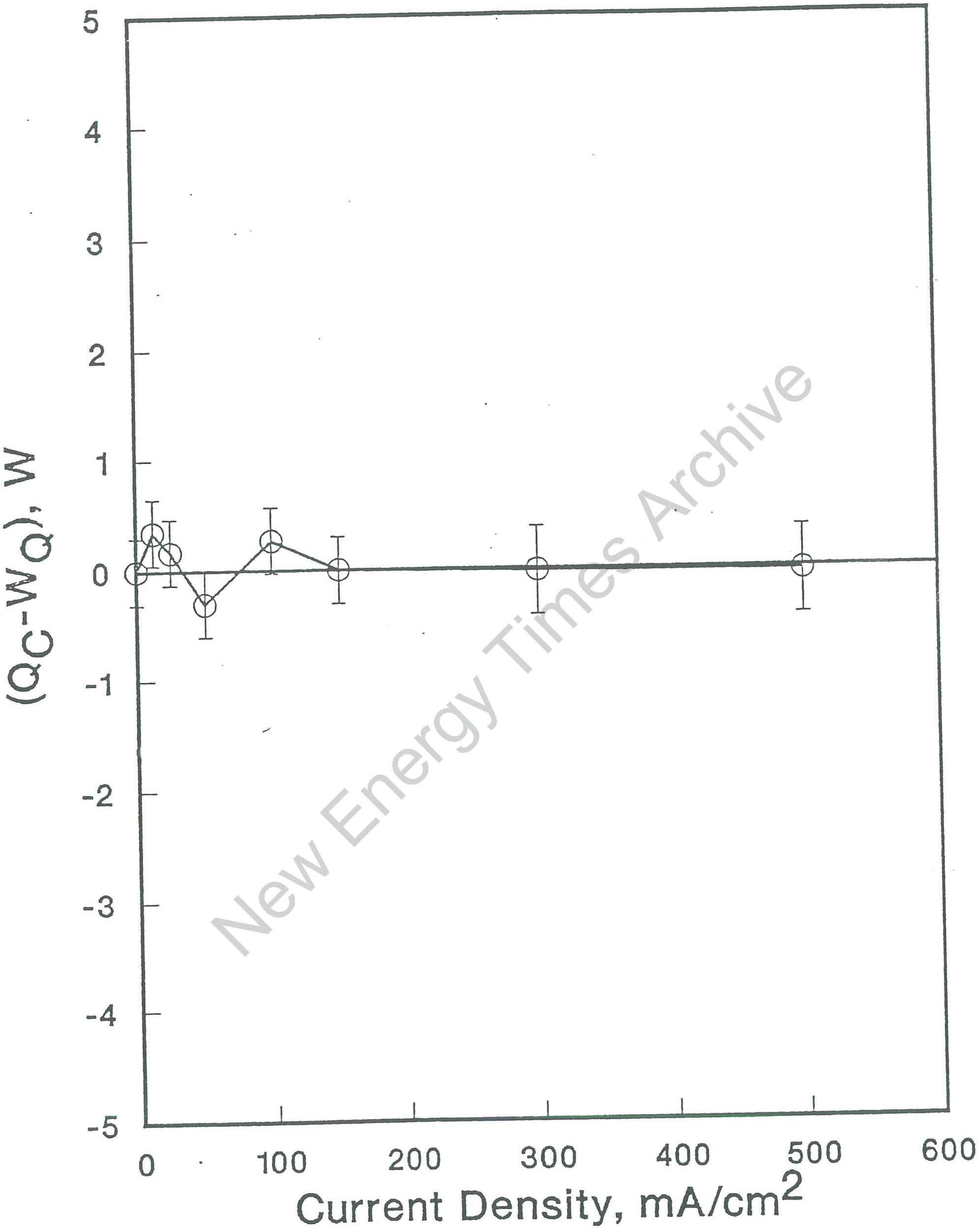

120
100
80
60
40
20
0
Current Efficiency, %
0
0.2
0.4
0.6
0.8
1
x in PdD$_x$


2.5
2
1.5
1
0.5
0
0.7
0.8
0.9
1
1.1
Degassing Rate, mg/min
x in PdD$_X$

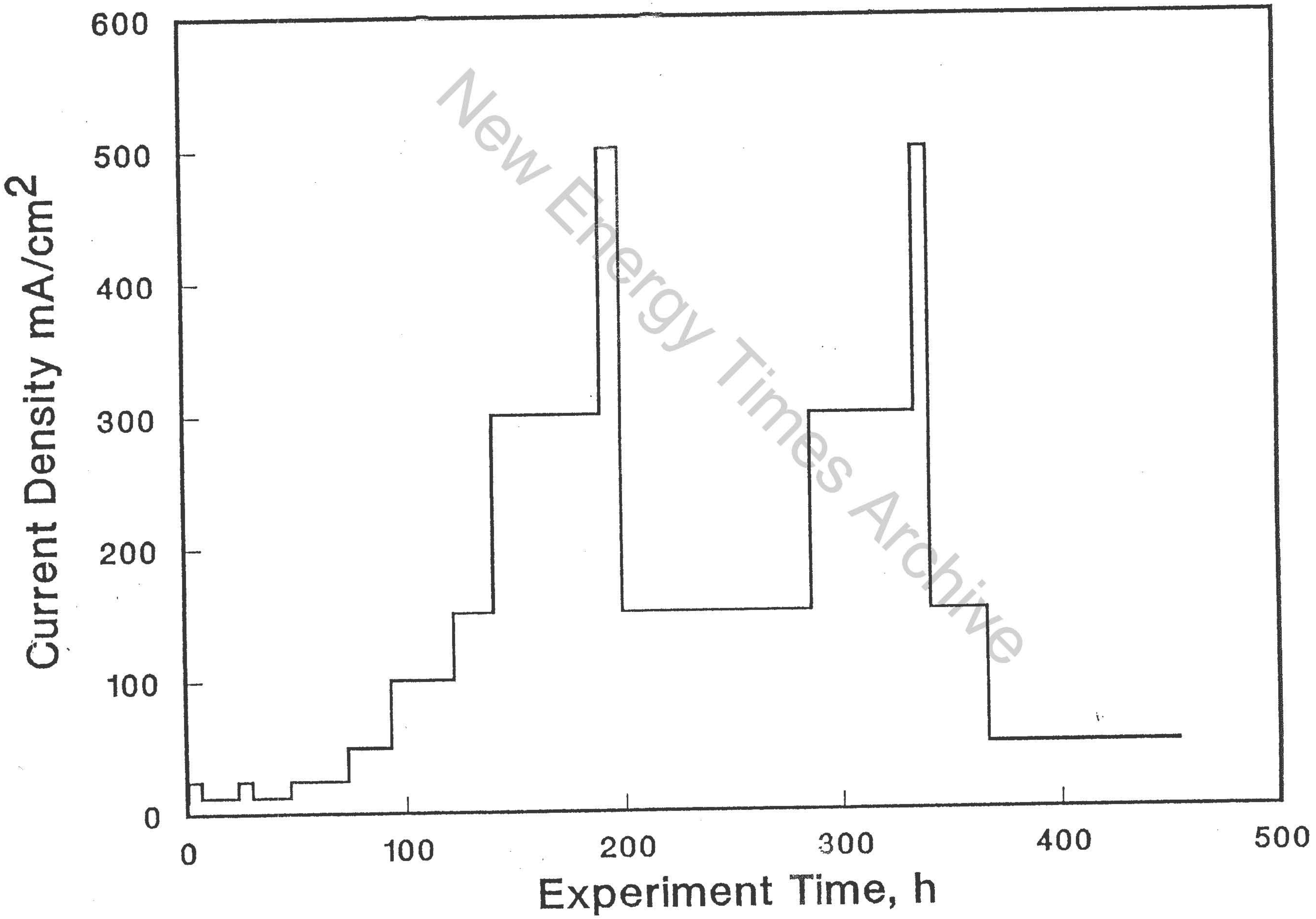


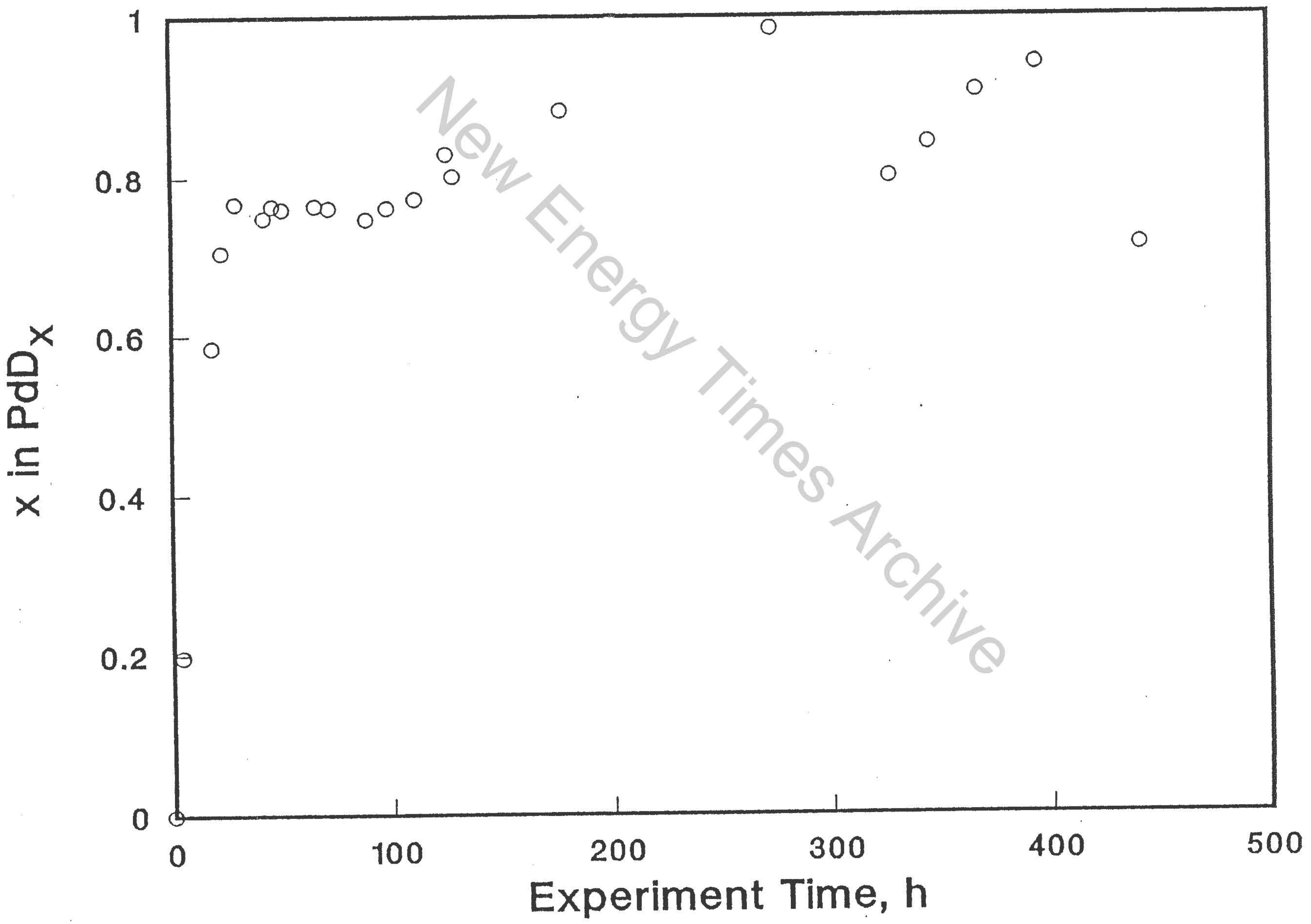
Cell Water Loss, mg/min
40
35
30
25
20
15
10
5
0
Theoretical Line for
No Recombination
0
100
200
300
400
500
600
Current Density, mA/cm^2


Pd-D Cell
○ = Q_C
■ = W_Q
Power, W
Current Density, mA/cm^2
0
2
4
6
8
10
12
14
16
18
20
0
100
200
300
400
500
600



5
4
3
2
1
0
-1
-2
-3
-4
-5
$(Q_C - W_Q)$, W
0
100
200
300
400
500
600
Current Density, mA/cm^2


600
500
400
300
200
100
0
Current Density mA/cm2
0
100
200
300
400
500
Experiment Time, h


x in PdDx
1
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
Experiment Time, h

SOME COLD FUSION MEASUREMENTS IN BUILDING 205

by

M. Tetenbaum, G. P. Felcher, M. Blander, and J. M. Carpenter

I. Cold Fusion Neutron Detector

We built two detectors for cold fusion experiments, both of the "long counter" type. One has a single high pressure ^{3}He proportional counter and a small polyethylene moderator for use as a background monitor, the other has eight high pressure ^{3}He proportional counters surrounding a central well for electrolytic cells in a 30x30x30 cm^3 polyethylene moderator; this is surrounded by 2.5 cm-thick B_4C shielding. The efficiency of the well detector, for fission neutrons from a 4900 n/sec ^{248}Cm spontaneous fission calibration source in the central well, is about 20%, and the background is approximately 22 counts per minute, consistent with rough estimates of the rate due to cosmic ray generated neutrons in the laboratory. The efficiency of the monitor detector, for a source 9 cm from the center, is about 0.8% and the background counting rate is about 1.7 counts per minute. The detectors are portable enough to enable the apparatus to be moved from one laboratory to another, or to an underground location.

II. Electrochemical Cell for Cold Fusion

We constructed electrochemical cells to test the cold fusion concept by measurements of the emission of neutrons. Jones *et al.* reported a small flux of neutrons from electrochemical cells using Au-Pd or Au-Ti couples in an electrolyte solution in heavy water. The neutron flux was low and the total number of neutrons produced was small enough to require a check that the results were not caused by a background fluctuation. Our experiment was designed primarily to check the results of Jones *et al.*

Our cells are contained in beakers of about 2 in. ID. The anode was an unannealed thick gold or platinum foil about 7x5 in. that was rolled into a cylinder and placed in the beaker. The tendency of the gold or platinum cylinder to expand kept the foils snug against the beaker wall. A Ti rod 5 mm in diameter or a Pd rod 6.4 mm in diameter was positioned in the center of the beaker and served as a cathode. About 30 cc of an 0.1 molar solution of LiOD in D_2O provided about 1.3 cm of electrolyte. A constant current was supplied to the cell by a Princeton Applied Research potentiostat-galvanostat and voltage was measured by a digital voltmeter. The current density was based at about 100 milliamps per square centimeter for both electrodes.

Our cells are supported in the central well of the detector and are surrounded by the eight high pressure ^{3}He proportional counters set in the 30x30x30 cm^3 polyethylene moderator. Background was generally measured before and after every run for 15 hours. Several initial runs were made for times ranging from 2 to 34 hours. The region around the high voltage detector components was purged with dry nitrogen to remove the deuterium generated and the evolved water mist. Actual neutron counts never differed significantly from background. The voltages of the cells varied considerably during a run ranging from ~10.6 V down to as low as 1.3 V for a very short period of time with a gold anode. Observations of the cell revealed a dark brown deposit on the gold anode and a dark "sludge" at the bottom of the beaker. There was a brownish deposit on the cathode in the heavy water. The sludge consisted largely of very fine gold particles and, aside from a brownish surface layer, the cathode deposit was gold. The gold anode electrochemically dissolved away during a run. The use of platinum as the anode seemed to solve this problem of electrochemical transfer. Such transfer could have stopped any fusion reaction in the experiments of Jones *et al.* since their gold anode would dissolve and plate out on their cathode (and also form a gold sludge) and thus block the cathode from picking up deuterium. This could explain why Jones' cell stopped giving an apparent neutron count after a brief time.

For all but two of the runs, the neutron counts were consistent with the background. For two successive runs, we had a false alarm, with the apparent number of counts rising significantly above the background. This was apparently due to the effect of a water mist emanating from the electrolyte that was generated mechanically by the bubbles of D_2 and O_2 being released from the cell. The mist shorted the detectors in a manner that increased the apparent neutron count. The apparatus was modified to doubly isolate the detectors from the cell by use of a "chimney" pipe above the electrolytic cell to conduct the cell offgas away from the well and a plastic bag in the well and between the chimney and the detectors. The space betwen the detectors and the plastic bag was flushed with dry N_2. With the detectors discussed above, we can make a very sensitive test of the results of Jones *et al.* using either Ti or Pd cathodes.

III. Measurements and Error Analysis

The minimum detectable ($\pm 1\sigma$) source rate, as is appropriate to the case of counting small signal rates, is for the case of a counting rate during electrolysis equal to the background rate

$$S^2_{max} = B\left(\frac{1}{T_S}+\frac{1}{T_B}\right)\Big/\epsilon^2 \qquad (1)$$

where B is the background counting rate, T_S is the counting time during electrolysis and T_B is the time for measurement of background, and ϵ is the detector efficiency (counts per neutron). A figure of merit for these measurements is therefore $\sqrt{B}/\epsilon$, which should be minimized in the detector arrangement. As our detector stands, B = 22 counts/min and $\epsilon = 0.20$, measured with a small (4900 n/sec) ^{248}Cm spontaneous fission neutron source. Thus, for a typical run of 13.2 hours for the background and 21.3 hours of counting with the electrochemical cell operating after the above modification of the apparatus, we did not detect a neutron flux above background. From Eq. (1) we calculate a value of $S_{max} = 1.06$ neutrons/min = 0.018 neutrons/sec. This result is to be compared with the result of Jones *et al.* who report observing a net of 0.06 neutrons/sec. We understand that the Harwell measurements have placed a limit $S_{max} \simeq 0.004$ neutrons per sec on the neutron emission rate from a Pons-Fleischmann cell. Our measurements are inconsistent with the results of

Jones *et al.* Our other runs are consistent with this conclusion. Similar results were observed with Au and Pt as anodes and Ti and Pd as cathodes.

Our results are inconsistent with the results of Jones *et al.* Since we have not yet performed measurements for as long times as suggested by Pons and Fleischman, our results do not necessarily refute their conclusions.

We were planning to continuously monitor neutron background with a duplicate detector system during the course of an extended run in the detector complex housing the Pd-Pt-LiOD electrochemical cell system. Unfortunately, the need for the neutron detectors and B_4C assembly for IPNS experiments curtailed these plans. However, it should be pointed out that similar long-term experiments have been performed at Harwell with negative results.

in an electrolytic cell with Pd-Pt electrodes

K. E. Rehm, W. Kutschera and G. J. Perlow

Physics Division, Argonne National Laboratory

The production of protons from the D(d,p)T reaction was investigated using an electrolytic cell connected to a proportional counter (PC). The cathode was a thin (31 mg/cm^2) Pd foil (area = 0.6 cm^2) separating the gas (a 90%- argon 10%-methane mixture) in the counter from the electrolyte (0.1 M LiOD in D_2O). The response of this detector setup to protons generated at various depth within the Pd foil was simulated in a Monte Carlo calculation and an efficiency of the PC for proton detection of 28% was calculated. The current densities in the cell ranged from 10-650 mA/cm^2. The setup has been in operation for about 8 weeks. Several runs with the current switched on and off, with different Pd foils, and with electrolytes of LiOD in D_2O and LiOH in H_2O have been performed with the longest individual run lasting more than 10 days. No difference in the counting rate was observed that could be attributed to the electrolytic cell being on or off. Since in addition to the energy measured in the PC the time for each event was recorded the time structure of the count rate could also be analyzed.

The main contributions to the background in the low energy region (E <20 keV), where effects from the tritium decay to ^{3}He are expected, are due to minimum ionizing particles in the cosmic ray flux. This count rate was found to be correlated to changes in the barometric pressure with a higher count rate observed at low barometric pressures. These pressure fluctuations can result in count rate variations up to ±4%. For this low energy regime the differences in count rate with the cell switched on or off were (1.8±9) 10^{-3} counts/sec (1σ-error).

For the high energy region, where events from protons from the D(d,p)T reaction are expected (E >120 keV), the main background is due to α-radioactivity in the detector material and the Pd-foil. In this energy regime the differences in count rate with the cell switched on or off were (0.96±2.54)10^{-4} counts/sec (1σ-error).

ANL

The experiment with a light water electrolyte showed no difference if compared to the heavy water electrolyte.

A Fourier analysis of the time structure showed no pronounced frequencies or bursts in the count rate.

Including the efficiency of the detector system an upper limit for the cold fusion rate of less than (2.1×10^{-3}) (2σ-error) has been obtained. With the assumption of a ratio between Pd and D of 1:1 an upper limit of 4×10^{-23} fusion-events/dd-pair/sec (2σ-error) has been deduced.

A detailed account of these results is currently being prepared for submission to Physical Review Series C (Nuclear Physics).

August 18, 1989

TO: Dieter M. Gruen CHM

FROM: S. Zaromb SZ ERD
S.J. Freedman PHY
D. Krakauer PHY
J.P. Greene PHY

RE: **Summary Update on "Cold Fusion" Tests**

The experiments described in our memo of 5/3/89 (attached herewith) have continued intermittently and at a low level of effort. Improvements were made in:

(a) the positioning of the silicon surface-barrier detector and in shielding it from extraneous sources (mainly ambient light);

(b) increasing the current density at the Pd cathode to about 0.6 A/cm^2 -- the range claimed by Appleby et al. to have resulted in excess heat generation; and

(c) maintaining a nearly constant level of electrolyte in the cell in spite of appreciable evaporation of D_2O under the conditions of electrolysis at high current densities.

Although the detector electronics recorded at one time a peculiar particle energy spectrum (with peaks at around 3 MeV and 6 MeV) when a 1 M $LiOD_2$ solution in D_2O was electrolyzed at a cathode current density $\geq$ 0.6 A/cm^2, the effect must be attributed to an experimental artifact, as similar spectra were recorded in some of our control runs. We have therefore decided to give up the measurements with the surface-barrier detector and to use, instead, an etch-pit counting approach. Experiments with etch-pit counts and high cathode current densities will be initiated at a low level of effort within the coming months.

SZ/mp

May 3, 1989

TO: Dieter M. Gruen CHM

FROM: S. Zaromb SZ BEM/CER
S.J. Freedman PHY
J.F. Last PHY
J.P. Greene PHY

Re: **Our "Cold Fusion" Tests**

1. APPROACH

The purpose of our experiments is to check whether the emission of charged nucleons (H^+, D^+, T^+, $^3He^{++}$ or $^4He^{++}$) might account for the excess energy generation that has been claimed by Fleischmann and Pons. In particular, the reaction $^6Li + D \rightarrow 2\ ^4He$, although extremely unlikely in vacuo due to a high Coulomb barrier, might conceivably be catalyzed in palladium by certain favorable instantaneous configurations of electron clouds. Such a reaction could generate alpha particles having sufficient energy (ca. 8 MeV) to pass through a 0.002-cm thickness of palladium. We therefore constructed an electrolytic cell in which a 2.5-cm diameter smooth Pt anode is parallel to and spaced by a 1.0-cm or 2.5-cm electrolyte gap from a similar 0.0025-cm thick Pd cathode whose back side can be exposed to a charged particles detector. The backside of the Pd cathode had a layer of ^6Li, 80 micrograms/cm^2 thick, evaporated in vacuo at 210-230°C within a 10-minute period and thereafter maintained in vacuo at 150-200°C for 5 hours to effect diffusion of the ^6Li into the palladium. The rationale for this treatment was to: a) block the back of the Pd with a Li-rich phase that might prevent or slow down the escape of deuterium from the Pd lattice; and b) introduce enough ^6Li into that lattice to permit the above reaction, if such a reaction can occur in Pd.

2. EXPERIMENTAL PROCEDURE AND RESULTS

2.1 Electrolysis Conditions

The cell electrolyte was 0.1 M LiOD in 99.8% D_2O. The applied current density was maintained at about 20 mA/cm^2 for the first 3 days and at about 40 mA/cm^2 for another two days until an electrolyte leak through pinholes in cathode necessitated interruption of the experiment.

silicon surface-barrier detector. The detector has a sensitive area of about 1 cm diameter and its distance to the palladium foil is some 5 mm. It is operated at 60 V bias voltage.

We use a standard setup for measuring the pulse height spectrum in the silicon detector. It consists of a CANBERRA preamplifier, an ORTEC 571 main amplifier and an ORTEC 811 peak-sensing CAMAC ADC. After conversion, the ADC is read out by a PC-based data taking system. The channel information is histogrammed and stored.

The discriminator threshold for the electronics was lowered into the detector noise and allowed typically 2-5 triggers per second. We also calibrated the system with a ^{273}Ca source.

2.2 Results

We have recorded pulse height spectra from the silicon detector under various conditions. These include background measurements with and without electrolyte, different palladium foils, and measurements of the operating cell with a lithium-plated palladium foil serving as the negative electrode. Data was taken overnight, one run accumulating data over a period of about 10 hours.

We observe condensation of (heavy?) water on the detector surface which, in most cases, caused a dramatic increase in detector noise and thus in count rate. The origin of the water is unclear. A possible source is deuterium that migrates through the foil and recombines with oxygen to water in the presence of palladium. These small amounts of water could then evaporate off the warm palladium foil. We saw no evidence of leakage from the cell until the fifth day of electrolysis.

None of the runs so far shows any significant count rate in the detector above some 50 keV. One measurement shows a noise spectrum that extends to almost 1 MeV, probably due to a detector malfunction.

3. DISCUSSION OF RESULTS AND CURRENT PLANS

We have to identify the source of the condensed water. Clearly a situation where water wets the silicon detector is not acceptable. After having solved this problem we will take more data under better-controlled conditions.

Our current efforts are directed at improving the gasketing around the cathode, and at preventing D_2O condensation on the detector by passing air through the chamber between the detector and the cathode. We are also preparing a new cathode made of 0.0013-cm thick Pd foil into which the evaporated ^{6}Li will be caused to diffuse for a longer time at a higher temperature (>60 hours at about 400°C). This will assure better Li penetration, which may, in turn, more effectively obstruct the escape of D_2 through the back side of the Pd cathode.